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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

AN ANALYSIS OF THE PROPULSION EXPERIMENTS PERFORMED ON A MODEL REPRESENTING THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP FITTED WITH TWO SETS OF DESIGN CONTRAROTATING PROPELLERS (MODEL 5362; PROPELLERS 4731 & 4732 AND 9019 & 9020)

by

Steven C. Fisher

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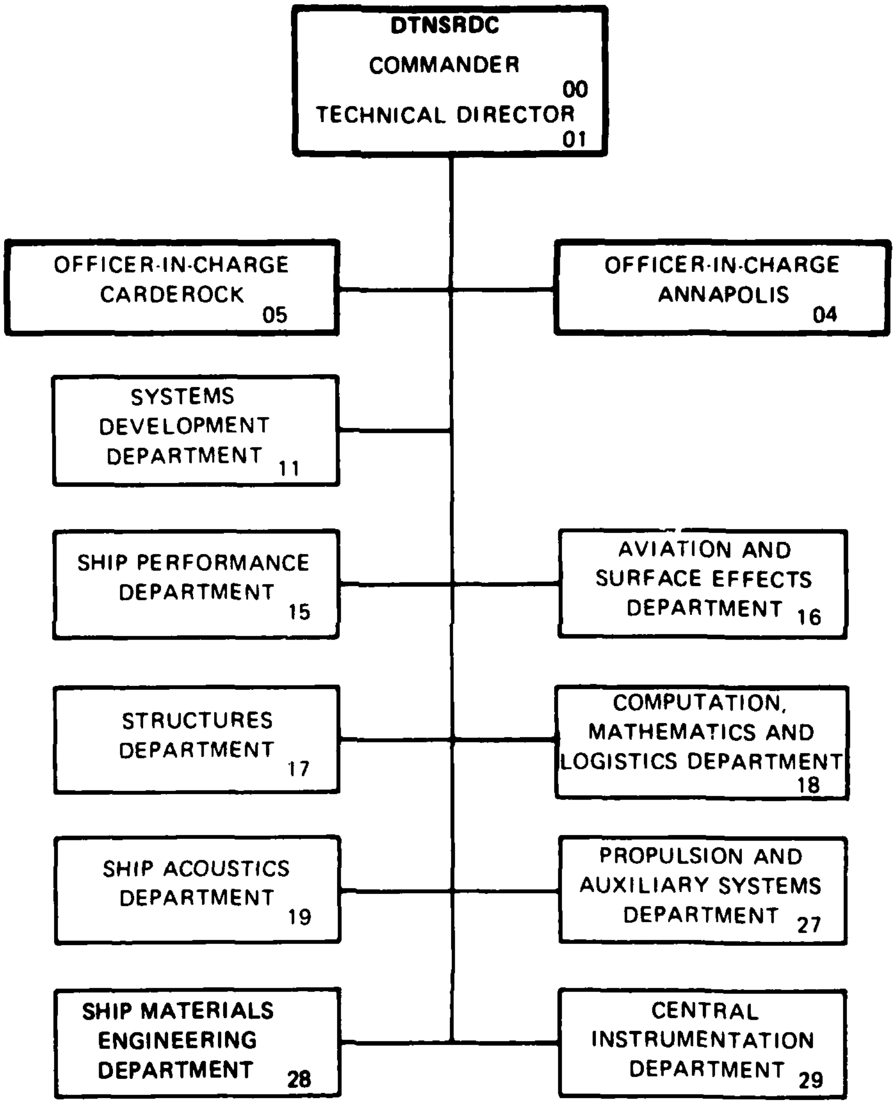

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A series of propulsion experiments were performed on Model 5362, representing a Stretched PONCE DE LEON Class RO/RO ship. The model was fitted with two sets of design contrarotating propellers. The results of the propulsion experiments indicate that the ship when equipped with either set of contrarotating propellers should achieve design speed with 12-13% less power than when fitted with the design single screw propeller. The methods used in analyzing the data are discussed.

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NOTATION

D		Diameter of propeller
J		Advance coefficient $(\frac{V_A}{nD})$
J_T	(JT)*	Advance coefficient based on thrust identity
K_Q		Torque coefficient = $\frac{Q}{\rho n^2 D^5}$
K_T		Thrust coefficient = $\frac{T}{\rho n^2 D^4}$
N		Propeller rpm
n		Propeller rps
P_D	(PS)	Delivered power at the propeller
P_E	(PE)	Effective horsepower
Q		Torque developed by propeller
R_T		Total resistance
T		Thrust developed by propeller
t		Thrust deduction fraction = $(T - R_T)/T$
V		Actual model or ship velocity
V_A		Propeller speed of advance
w_T	(WT)	Taylor wake fraction determined from the thrust identity
w_Q	(WQ)	Taylor wake fraction determined from the torque identity
η_D	(ETAD)	Propulsive coefficient = P_E/P_D
η_H	(ETAH)	Hull efficiency
η_R	(ETAR)	Relative rotative efficiency

*Computer language notation used in tables is shown in brackets

η_o	(ETAO)	Open water propeller efficiency
ρ		Water density
ΔZ		Axial distance between the leading and trailing edges of a propeller blade at a given radius (used to calculate pitch)
$\Delta\theta$		Angle measured in the propeller disk plane between the leading and trailing edge of the propeller blade at a given radius (used to calculate pitch)

<u>Subscripts</u>

F	Forward propeller
A	After propeller

ENGLISH/SI EQUIVALENTS

1 degree (angle)	= 0.01745 rad (radians)
1 foot	= 0.3048 m (meters)
1 foot per second	= 0.3048 m/sec (meters per second)
1 inch	= 25.40 mm (millimeters)
1 knot	= 0.5144 m/s (meters per second)
1 lb (force)	= 4.448 N (Newtons)
1 lb (force) - inch	= 0.1130 N·m (Newton-meter)
1 long ton (2240 lb)	= 1.016 metric tons, or 1016 kilograms
1 horsepower	= 0.746 kW (kilowatts)

ABSTRACT

A series of propulsion experiments were performed on Model 5362, representing a Stretched PONCE DE LEON Class RO/RO ship. The model was fitted with two sets of design contrarotating propellers. The results of the propulsion experiments indicate that the ship when equipped with either set of contrarotating propellers should achieve design speed with 12-13% less power than when fitted with the design single screw propeller. The methods used in analyzing the data are discussed.

ADMINISTRATIVE INFORMATION

This project was authorized and funded by the Naval Materials Command (NAVMAT) Ship Performance and Hydromechanics Program under Program Element 62543N, Subproject Number 43-421-001, Work Unit 1-1500-104-10.

INTRODUCTION

The results[1] of the initial propulsion experiments with a model of the stretched PONCE DE LEON (SPDL) Class RO/RO ship fitted with contrarotating propellers indicated that the thrust deduction values may be effected by the relative longitudinal position of the propeller set. Further, the design torque ratio of the propellers was not met. A project was supported by the Naval Material Command (NAVMAT) to determine the effects of the relative longitudinal position of the propellers and rpm ratio on the propulsive characteristics of the SPDL.

Propulsion experiments were performed on Model 5362, representing a Stretched PONCE DE LEON Class RO/RO ship, using two sets of design contrarotating propellers. One set of propellers was designed at DTNSRDC, and the other set was designed by the LIPS Propeller Works (LIPS) in the Netherlands. These propellers were designed using data from earlier wake survey experiments on Model 5262.

[1] References are listed on page 15.

The first series of propulsion experiments were performed in November 1978, with the model at the full load and ballast displacements. The contrarotating propellers were driven at a fixed rpm ratio of 1.0. The torque ratio, thrust deduction, and propulsive coefficient values were lower than was expected. Also, the differences between the thrust deduction values for the two sets of design contrarotating propellers were larger than expected. One possible explanation for the differences in the thrust deduction values was the fact that the LIPS propellers were designed so that the aft propeller was closer to the rudder than was the aft DTNSRDC propeller.

Additional propulsion experiments were undertaken in April 1979 to repeat some of the earlier experiments and to examine the effects of propeller location on the propulsive performance. Alterations were made to allow the DTNSRDC propellers to be moved aft to the LIPS design position, and the LIPS propellers to be moved forward to the DTNSRDC design position. In addition, propulsion experiments were performed on the model using the DTNSRDC design contrarotating propellers driven at a fixed rpm ratio of 1.05. All of the propulsion experiments in April 1979 were performed with the model at the full load displacement.

The new propulsive coefficient, thrust deduction, and torque ratio values were more reasonable. However, there still were problems with the thrust measurements, particularly as shown by the thrust ratio values.

The results of the propulsive experiments from November 1978 and April 1979 have been analyzed and reported[1]. This report discusses the difficulties with the data, and presents the methods used to analyze the data to obtain meaningful results.

EXPERIMENTAL ARRANGEMENT

Model 5362 was constructed from wood to represent a Stretched PONCE DE LEON (SPDL) Class RO/RO Ship, using a linear ratio of 25.20. The model and ship dimensions are presented in Table 1, and the stern lines drawing is shown in Figure 1.

The model was ballasted for testing at representative full scale conditions of (a) full load displacement of 30,060 tons (30,540 t) and draft of 27.0 feet (8.23 m) at an even keel, and (b) ballast displacement of 22,535 tons (22,900 t) and drafts of 16 feet (4.88 m) at the bow and 27 feet (8.23 m) at the stern.

Two sets of design contrarotating propellers were used in the propulsion experiments. The first set, consisting of Propellers 4731 and 4732, were designed and built at DTNSRDC. The second set, consisting of Propellers 9019 and 9020, were designed by the LIPS Propeller Works and built at the Netherlands Ship Model Basin (NSMB). Figures 2 and 3 show photographs of the DTNSRDC and LIPS design propellers, Figures 4 to 5 show the propeller drawings, and Tables 2 to 5 compare offsets from the model propellers with the design values.

The LIPS propellers are designed so that the aft propeller is closer to the rudder than is the aft DTNSRDC propeller. Alterations were made to both propeller sets to allow the DTNSRDC propellers to move aft to the LIPS propellers design position, and the LIPS propellers to move forward to the DTNSRDC propeller design position. This represents a shift in propeller position of 0.56 m (1.84 feet) at the full scale. Figures 8 and 9 show the model with the propellers in their design position, and Figures 10 and 11 show the model with the propellers in the exchanged positions. These alterations were made by attaching different thickness spacers to the front of the DTNSRDC and LIPS forward propeller hubs. A shorter fairwater is used with the DTNSRDC propellers in the aft position because the original fairwater would interfere with the rudder.

The contrarotating propeller shafting consists of a solid inner shaft and a hollow outer shaft. The inner shaft bearings are inside the hollow shaft, and the bearings for the hollow shaft are positioned in the model as for a normal single shaft propulsion arrangement. Both shafts deliver power to the propeller from a single motor using a pair of gearboxes to divide the power between the two shafts. By using different gearboxes, the rpm ratio (N_F/N_A) can be altered. Since the shafting has to be adjusted every time the propellers are changed, the gearboxes and dynamometers are mounted on a steel base plate near the stern of the model to reduce shafting and dynamometer alignment problems.

DISCUSSION OF EXPERIMENTS AND MEASURED DATA

OPEN WATER EXPERIMENTS

In order to characterize the propellers, open water experiments for both pairs of design contrarotating propellers were performed prior to the November 1978 and April 1979 propulsion experiments. The experiments were performed in the deep water basin at DTNSRDC using the Center's propeller boat. The two propellers were not geared together, but both propeller rpm's were carefully adjusted to achieve an rpm ratio (N_F/N_A) of 1.0. Another series of open water experiments were performed in May 1980 with the DTNSRDC propellers operating at an rpm ratio (N_F/N_A) of 1.05.

Figures 12 to 15 show the unit and individual open water curves for the DTNSRDC and LIPS design propellers from the November 1978 open water experiments and Figures 16 to 19 from the April 1979 open water experiments at an rpm ratio (N_F/N_A) of 1.0. Figures 20 and 21 show the unit and individual open water curves for the DTNSRDC design propellers at an rpm ratio (N_F/N_A) of 1.05 from the May 1980 open water experiments. The thrust ratios (T_F/T_A) and torque ratios (Q_F/Q_A) are also plotted on the unit open water curves. It should be noted that the experimental accuracy for open water experiments with contrarotating propellers is considered to be $\pm$ 3 percent. The coefficients for the unit open water curves are defined as follows:

$$J = \frac{V_A}{n_F D_F}\ ,\quad K_T = \frac{(T_F+T_A)}{\rho\, n_F^{\,2} D_F^{\,4}}\ ,\quad K_Q = \frac{(Q_F \cdot n_F + Q_A \cdot n_A)}{\rho n_F^{\,3}\ D_F^{\,5}}\quad \text{and}\quad \eta_o = \frac{K_T\ .\ J}{K_Q\ .\ 2\pi}\ .$$

The coefficients for the forward propeller open water curves are defined as,

$$J_F = \frac{V_A}{n_F D_F}\ , \quad K_{T_F} = \frac{T_F}{\rho n_F^2 D_F^4}\ , \quad K_{Q_F} = \frac{Q_F}{\rho n_F^2 D_F^5}\ , \quad \text{and } \eta_{o_F} = \frac{K_{T_F} \cdot J_F}{K_{Q_F} \cdot 2\pi}\ ;$$

and the coefficients for the aft propeller open water curves are defined as,

$$J_A = \frac{V_A}{n_F D_F}\ , \quad K_{T_A} = \frac{T_A}{\rho n_F^2 D_F^4}\ , \quad K_{Q_A} = \frac{Q_A \cdot n_A}{\rho n_F^3 D_F^5}\ , \quad \text{and } \eta_{o_A} = \frac{K_{T_A} \cdot J_A}{K_{Q_A} \cdot 2\pi}\ .$$

The open water coefficients are based on the forward propeller rpm and diameter; and it should also be noted that the torque developed by the after propeller has been adjusted by a factor of n_A/n_F in the equations for K_Q and K_{Q_A}. This is to permit the definition of the torque coefficient (K_Q) for the contrarotating propeller set as the sum of the individual propeller torque coefficients.

DTNSRDC DESIGN CONTRAROTATING PROPELLERS

RPM RATIO OF 1.0

The DTNSRDC design contrarotating propellers operated in a range of J values (based on thrust identities) from 1.0 to 1.1 over a ship speed range of 8.24 m/s (16 knots) to 13.38 m/s (26 knots). There was a drop in open water efficiency values from the November 1978 to the April 1979 open water experiments.

Over the range of J values from 1.0 to 1.1, the forward propeller showed an average decrease in η_o values of 2.4 percentage points from November 1978 to April 1979. The aft propeller showed an average decrease in η_o values of 3.1 percentage points, and the propellers operating as a unit showed an average decrease in η_o values of 2.8 percentage points from November 1978 to April 1979. The drop in η_o values was caused by an increase in the torque values from both propellers during the April 1979 open water experiments.

Even though the thrust and torque values increased for both propellers during the April 1979 open water experiments, there was very little change in the torque ratio (Q_F/Q_A) and thrust ratio (T_F/T_A) values.

RPM RATIO OF 1.05

The DTNSRDC design contrarotating propellers operated in a range of J values from .98 to 1.04 over a ship speed range of 8.24 m/s to 13.38 m/s. There was virtually no change in unit open water efficiency between an rpm ratio (N_F/N_A) of 1.05 and an rpm ratio of 1.0.

At the J values corresponding to the ship speed of 11.9 m/s (23.1 knot the forward propeller showed an increase in η_o values of 2.9 percentage points from an rpm ratio of 1.0 to an rpm ratio of 1.05. The aft propeller showed decrease in η_o values of 2.4 percentage points, and the propellers operating as a unit showed a small increase in η_o values, 0.7 percentage points, from an rpm ratio of 1.0 to an rpm ratio of 1.05. It should be noted that the values used in this comparison for an rpm ratio of 1.0 were the averages from the November 1978 and April 1979 open water experiments.

LIPS DESIGN CONTRAROTATING PROPELLERS

The LIPS design contrarotating propellers operated in a range of J values from 0.95 to 1.05 over a ship speed range of 8.24 m/s to 13.38 m/s. There was a decrease in open water efficiency values with the forward propeller from November 1978 to April 1979. The open water efficiency values from the aft propeller and the propellers operating as a unit showed an increase.

Over the range of J values from 0.95 to 1.05, the forward propeller showed an average decrease in η_o values of 0.8 percentage points from November 1978 to April 1979. The aft propeller showed an average increase in η_o values of 3.4 percentage points, and the propellers operating as a unit showed an increase in η_o values of 1.3 percentage points from November 1978 to April 1979. The decrease in η_o with the forward propeller is due to a small increase in measured torque, and the increase in η_o with the aft

propeller and the propellers acting as a unit is due to a decrease in measured torque from the aft propeller from the April 1979 open water experiments.

The thrust ratio values from J = 0.95 to 1.05 showed little change from November 1978 to April 1979, but the torque ratio values showed an average increase of 0.05 in April, a change of approximately four percent.

PROPULSION EXPERIMENTS

Propulsion experiments were performed on Model 5362 in the deep water basin at DTNSRDC. Appendix A contains the data from the model propulsion experiments. The results from the experiments with the DTNSRDC and LIPS design contrarotating propellers for the ballast displacement are shown in Figures 22 to 24, , and for the full load displacement are shown in Figures 25 to 34. The results are also presented in tabular form in Tables 6 to 18. The ITTC correlation line was used with a C_A = 0.00025 for the model-ship correlation allowance.

The experiments performed in November 1978 included propulsion experiments at the full load and ballast displacements with the DTNSRDC and LIPS design contrarotating propellers in their design positions. The experiments performed in April 1979 included propulsion experiments with the DTNSRDC and LIPS design contrarotating propellers in both the forward position (DTNSRDC design position) and aft position (LIPS design position) at the full load displacement only. Unless otherwise noted, the propeller sets are in their design position. There was an additional propulsion experiment with the DTNSRDC propellers in their design position, using an rpm ratio (N_F/N_A) of 1.05 instead of 1.0. Unless otherwise noted, the propellers are operating at an rpm ratio (N_F/N_A) of 1.0.

PROPULSIVE COEFFICIENT

The values of the propulsive coefficient, η_D, associated with the model at the full load displacement and fitted with the LIPS design contrarotating propellers show good repeatability between the

November and April propulsion experiments. The values are identical up to 12.1 m/s (23.5 knots), when the propulsive coefficient curve from the April experiments begins to drop relative to the November 1978 curve. The difference between the two curves is one and a half percentage points at 13.4 m/s (26 knots), which is within the experimental accuracy.

The values of the propulsive coefficient η_D associated with the model at the full load displacement and fitted with the DTNSRDC design contrarotating propellers differ from the November 1978 to the April 1979 propulsion experiments. At 11.9 m/s (23.1 knots), η_D from the November experiments is 0.758, and the η_D value from the April experiments is 0.785. Since the difference in the values of η_D is within the experimental accuracy, it was decided to use the average of the η_D values from November and April. Because the average value of η_D is used, the values of η_D for the model at the ballast displacement and also at the full load displacement with the propellers moved aft have been raised or lowered to keep the relationships between the two displacements and two propeller positions the same. Therefore, the η_D value at 11.9 m/s (23.1 knots) for the model at the ballast condition is raised from 0.765 to 0.775, the η_D value for the model with the DTNSRDC propellers moved aft is lowered from 0.780 to 0.765, and the η_D value for the model with the DTNSRDC propellers at an rpm ratio of 1.0 is lowered from 0.775 to 0.760.

At the design speed, 11.9 m/s (23.1 knots), the propulsive coefficient associated with the DTNSRDC propellers is greater than or equal to that associated with the LIPS propellers, i.e., 0.770 and 0.775 for the DTNSRDC propellers compared to 0.765 and 0.775 for the LIPS propellers at the full load and ballast displacements, respectively. If the LIPS propellers were moved forward from their design position to the design position for the DTNSRDC propellers, the η_D value with the LIPS propellers would increase to 0.775. Conversely, if the DTNSRDC propellers were moved aft to the LIPS design position, the η_D value would decrease to 0.765.

It should be noted that all of these differences are within experimental accuracy. Because of this, the propulsive performance of the two sets of propellers is considered to be equivalent.

The propulsive coefficient value associated with the DTNSRDC propellers at a ship speed of 11.9 m/s (23.1 knots) decreases from 0.770 at an rpm ratio of 1.0 to 0.760 at an rpm ratio of 1.05. Because the results for both rpm ratios are basically the same, there is no significant effect due to not running at the design torque ratio.

A comparison of the powering characteristics of the single screw propeller to both sets of contrarotating propellers at the ballast displacement is given in Table 19 . These results indicate that the contrarotating propellers are 12-13% more efficient than the existing single screw propeller at 23.1 knots. Because the only model propulsion experiments using a single screw propeller were performed with the model at the ballast displacement, there can be no comparison of the powering characteristics with the model with either set of contrarotating propellers at the full load displacement. However, a similar improvement in efficiency is expected at the full load displacement with the contrarotating propellers.

THRUST DEDUCTION

The difference between the thrust deduction values from the November 1979 experiments with the two pairs of contrarotating propellers was larger than expected. For the design speed of 11.9 m/s (23.1 knots) and the full load displacement, the thrust deduction value for the model fitted with the DTNSRDC propellers was 0.915, compared to a thrust deduction value of 0.860 for the model fitted with the LIPS propellers. One possible explanation of this difference was the fact the the LIPS propellers were designed so that the aft propeller was closer to the rudder than the aft DTNSRDC propeller. To further clarify this difference, additional experiments were undertaken in April 1979. Alterations were made to allow the DTNSRDC propellers to be moved aft to the LIPS design position, and the LIPS propellers to be moved forward to the DTNSRDC design position.

The thrust measured from both pairs of contrarotating propellers was higher during the April 1979 experiments than during the November 1978 experiments. The values of the thrust deduction at 11.9 m/s (23.1 knots)

from the April 1979 experiments for the DTNSRDC propellers were 0.940 and 0.965, and for the LIPS propellers were 0.975 and 0.950, for the propellers in the forward (DTNSRDC) and aft (LIPS) positions, respectively. The difference between the values of the thrust for the DTNSRDC and LIPS propellers in their respective design positions is more acceptable, and it should be noted that the difference in the values of the thrust between each of the two propeller sets in the two different positions is within the experimental accuracy. Because of the better agreement in thrust values from the April experiments, the thrust measurements from the November experiments appear to be in error. The previously reported data are based on the results from the April 1979 experiments.

The thrust deduction value measured with the DTNSRDC propellers operating at an rpm ratio (N_F/N_A) of 1.05 was 0.90 at 11.9 m/s (23.1 knots), much lower than the values associated with an rpm ratio of 1.0. This low value indicates that there were some problems in the thrust measurements.

The variations in the thrust deduction mentioned earlier serve to illustrate the difficulties associated with obtaining good thrust measurements from contrarotating propulsion experiments. These difficulties are further aggravated by the long lengths of shafting required by the propulsion arrangement on the Stretched PONCE DE LEON model. Because of the possibility of errors in the thrust measurements from the November experiments, special care was taken in eliminating the probable sources of these difficulties before the April experiments, including repolishing the propeller shafts and replacing the shaft bearings.

TORQUE RATIO

Both the DTNSRDC and the LIPS design contrarotating propellers were designed to meet a torque ratio (Q_F/Q_A) of 1.278 at 23.1 knots with an rpm ratio of 1.0. The torque ratio values measured during the November 1978 experiments were 0.965 and 0.940 for the DTNSRDC propellers, and 1.140 and 1.115 for the LIPS propellers at the full load and ballast displacements, respectively.

One of the reasons for repeating the propulsion experiments in April 1979 was because the propellers did not reach their design torque ratio. The torque ratio values measured during the April 1979 propulsion experiments at the full load displacement was 0.903 and 0.909 for the DTNSRDC propellers and 1.189 and 1.183 for the LIPS propellers in the forward (DTNSRDC) and aft (LIPS) propeller positions, respectively. Again, neither propeller set met the design torque ratio, and there was a decrease in the torque ratio values measured for the DTNSRDC propeller from November to April.

One possible source of these differences in torque ratio values is insufficient accuracy in the propeller manufacture. Tables 2 to 5 contain propeller measurements taken after the experiments were completed. These measurements indicate that the average pitch is 1.6 and 1.0 percent lower than the design value on the DTNSRDC propellers (propellers 4731 and 4732, respectively). The average pitch is 0.7 and 1.2 percent higher than the design value on the LIPS propellers (propellers 9019 and 9020, respectively). These differences in pitch from the design values may account for some of the differences in the torque ratio. The lower measured pitch of the DTNSRDC propellers may account for the fact that the DTNSRDC propellers are operating at 92.4 RPM rather than the 90 RPM at which they were designed to operate.

If the propellers were to operate at a torque ratio of 1.278 either the pitch or the RPM ratio of the propellers would have to be changed. To quantify the change in pitch which would be required to meet the design criteria, the DTNSRDC design propellers were evaluated at an RPM ratio (N_F/N_A) of 1.05 in April 1979. This was equivalent to increasing the pitch of the forward propeller by 5 percent. The torque ratio values measured using the higher RPM ratio increased to 1.220 at 23.1 knots. This torque ratio was achieved with no loss in propulsive efficiency.

A linear extrapolation of these results using a torque ratio of 0.909 at an RPM ratio of 1.0 and a torque ratio of 1.220 at an RPM ratio of 1.05, yields an RPM ratio of 1.06 for a torque ratio of 1.278. This means that the desired torque ratio can be achieved by either accepting an RPM difference of 5 or 6 RPM between the forward and after propeller or by changing the pitch of the propellers. If the propeller pitch is to be changed, the desired torque ratio can be obtained by either

increasing the pitch of the forward propeller 5 to 6 percent (taking the error in manufacture into account), or by increasing the pitch of the forward propeller by 2 to 3 percent and decreasing the pitch of the after propeller by a similar amount. Such design changes should not be undertaken without a detailed analysis; but the desired torque ratio can probably be obtained without loss in propulsive performance. Similar changes, though smaller, could be made for the LIPS propellers to bring them up to the design torque ratio.

Thrust Ratio

The model fitted with either set of contrarotating propellers shows an increase in the thrust ratio values from the November 1978 to the April 1979 propulsion experiments. The thrust ratio values from the November propulsion experiments at the design speed, 11.9 m/s (23.1 knots) are 0.785 and 0.770 for the DTNSRDC propellers and 1.095 and 1.060 for the LIPS propellers in the full load and ballast conditions, respectively. The thrust ratio values from the April propulsion experiments are 0.826 and 0.875 for the DTNSRDC propellers and 1.189 and 1.183 for the LIPS propellers in the forward (DTNSRDC) and aft (LIPS) propeller positions, respectively. Since there were problems with the thrust measurement during the November experiments, the thrust ratio values from the April experiments at an rpm ratio of 1.0 are assumed to be correct. The increases in the thrust ratio values in April are mainly due to larger thrust values measured from the forward propellers.

The thrust ratio values of the DTNSRDC propellers at 11.9 m/s (23.1 knots), and operating at an rpm ratio of 1.05, is 0.952, higher than that associated with the propellers operating at an rpm ratio of 1.0.

It should be noted that there were problems with the unfaired thrust ratio values, shown in Figures 35 to 43. These problems, consisting of large amounts of scatter or unreasonable values, were most noticeable with the model fitted with the LIPS propeller,or with the DTNSRDC propellers at an rpm ratio of 1.05,from the April 1979 propulsion experiments. Some of the bad values corresponded to unreasonable thrust deduction values (1-t near or greater than 1.0). When these problems were significant, the open water thrust ratio curves were used as guides in fairing the thrust ratio curves.

The ratio of the propulsive coefficient of the forward propeller to that of the aft propeller, (η_{DF}/η_{DA}), can be used to analyze the relationship between the thrust and torque ratio values. The ratio η_{DF}/η_{DA} is equivalent to the ratio of the thrust ratio to the torque ratio, $(T_F/T_A)/(Q_F/Q_A)$, divided by the rpm ratio, (N_F/N_A). A value of η_{DF}/η_{DA} significantly different from 1.0 will indicate that there are problems with either the thrust or torque measurements. It should be noted that η_{DF}/η_{DA} as defined here is a simple tool for examing possible problems with the thrust or torque values, and should only be considered as such.

The value of η_{DF}/η_{DA} from the April experiments at 11.9 m/s (23.1 knots) is 0.91 for the DTNSRDC propellers, compared to 0.99 for the LIPS propellers. The small difference in η_{DF}/η_{DA} between the DTNSRDC and LIPS propellers (compared to the differences between the thrust and torque ratios) implies that the lower thrust ratios of the DTNSRDC propeller are compensated by their lower torque ratios.

The thrust ratio values associated with the DTNSRDC design contrarotating propellers are much lower than the thrust ratio values associated with the LIPS design contrarotating propellers. However, due to the lower torque ratio values of the DTNSRDC propellers, the ratios η_{DF}/η_{DA} are not all that much different.

At a J value corresponding to 11.9 m/s (23.1 knots), the DTNSRDC forward propeller open water efficiency increases, and the aft propeller open water efficiency decreases in changing from an rpm ratio of 1.0 to an rpm ratio of 1.05. This would indicate that $\eta_{DF}\ \eta_{DA}$ should increase since the ratio of the open water efficiencies of the forward to the aft propeller increases. However, the η_{DF}/η_{DA} value decreased from 0.91 at an rpm ratio of 1.0 to 0.743 at an rpm ratio of 1.05.

The low η_{DF}/η_{DA} value for the DTNSRDC propellers at $N_F/N_A = 1.05$ is not due to problems with the torque ratios (since the open water efficiency and the propulsive coefficients for both rpm ratios are within the experimental accuracy) but is due to problems with the thrust measurements. The low thrust ratio values combined with the low thrust deduction values indicate that the measure forward propeller thrust values may be lower than the actual forward propeller thrust values.

CONCLUSIONS

1. Because the difference between propulsive coefficient values at the design speed of 11.9 m/s (23.1 knots), for the ship fitted with both the LIPS and the DTNSRDC contrarotating propellers, is within the experimental accuracy, the propulsive performance of the ship fitted with either of the two sets of propellers is considered to be identical.

2. Model experiments conducted in the ballast condition indicate that the contrarotating propellers are 12-13% more efficient than the existing single screw propeller. A similar improvement in efficiency is expected at the full load displacement.

3. Small differences in the longitudinal position of the propeller sets have effects on the propulsive performance that are within the experimental accuracy.

4. A small change in the propeller rpm ratio (N_F/N_A) can greatly increase the torque ratio (Q_F/Q_A) while having effects on the propulsive coefficient that are within the experimental accuracy.

5. Because neither the DTNSRDC nor LIPS propeller sets meet the required torque ratio (Q_F/Q_A), an additional propulsion experiment was conducted with the model fitted with the DTNSRDC propellers operating at N_F/N_A = 1.05 to investigate the amount of propeller pitch change or the rpm ratio needed to reach the design torque ratio. A linear extrapolation using the torque ratios from experiments with N_F/N_A = 1.0 and N_F/N_A = 1.05 indicate that the DTNSRDC propellers will meet the desired torque ratio at an rpm ratio of 1.05 or with a 6 percent change in pitch; with no change in propulsive coefficient. Similar changes, though smaller, could be made for the LIPS propellers to bring them up to the design torque ratio.

6. The open water thrust ratio values can be used as a guide in fairing thrust ratio values that seem unreasonable or show a large amount of scatter.

REFERENCES

1. Forrest, A.W., and G.C. Swensson, "Application of Contrarotating Propulsion System to a U.S. Flag Merchant Vessel. Phase 1--Model Testing and Preliminary Installation Design", MA-RD-920-80072, (July 1980)

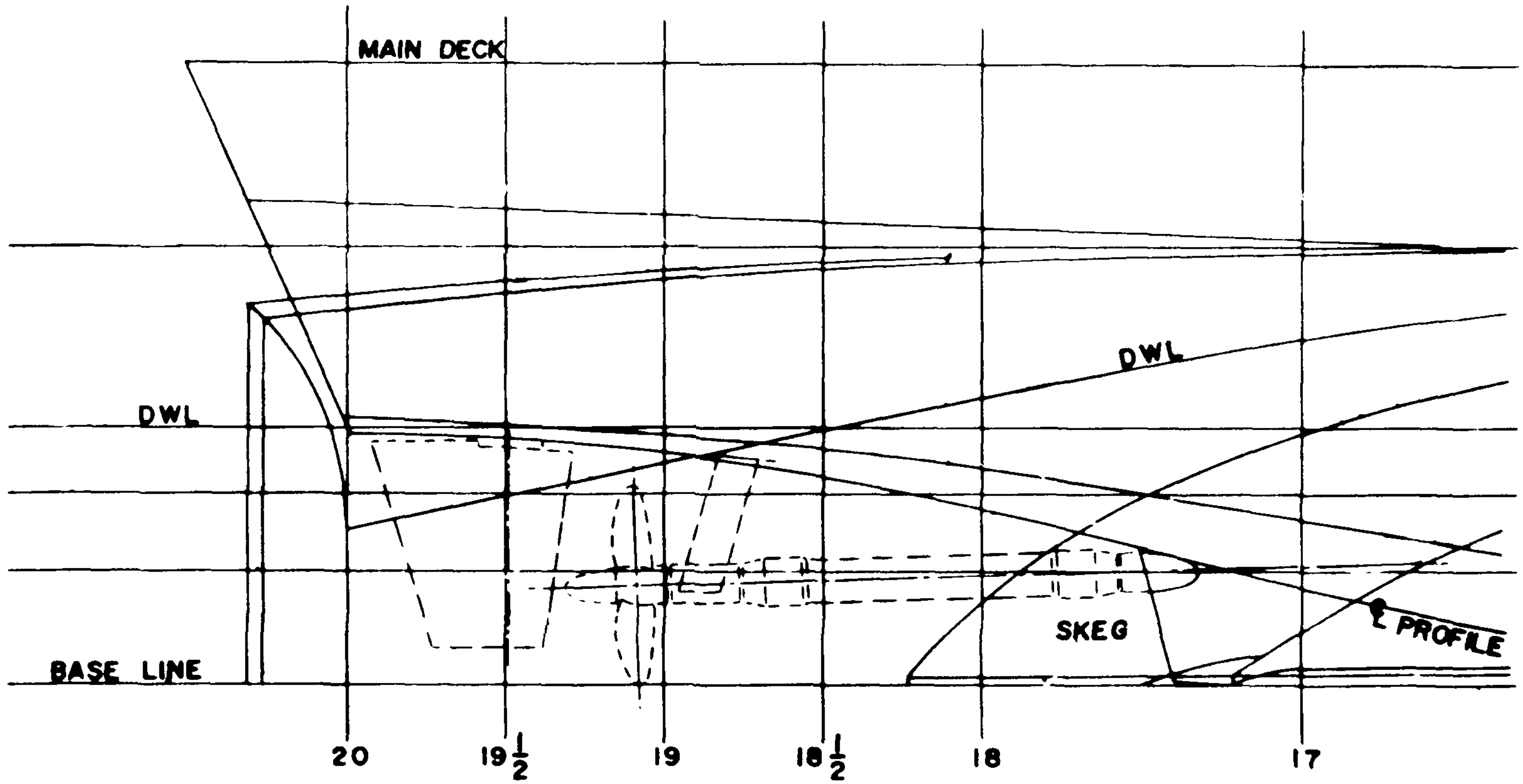
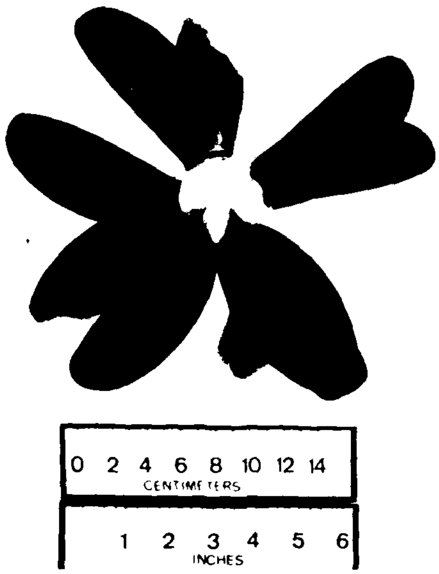


Figure 1 - Abbreviated Profile and Stern Lines of Model 5362



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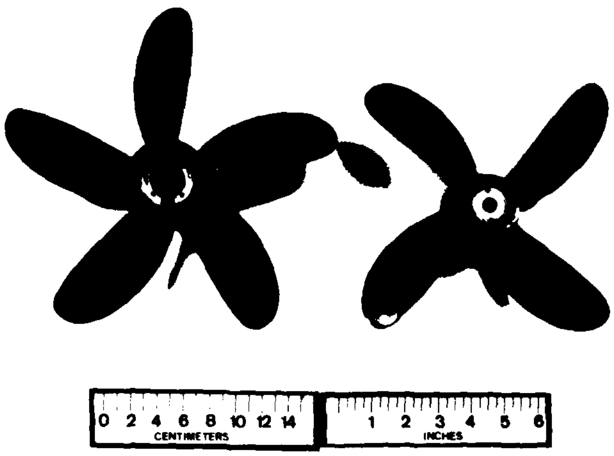
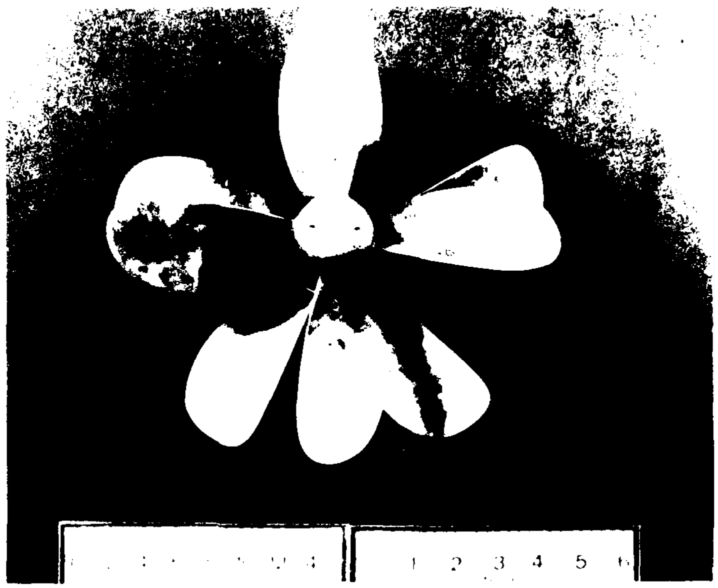
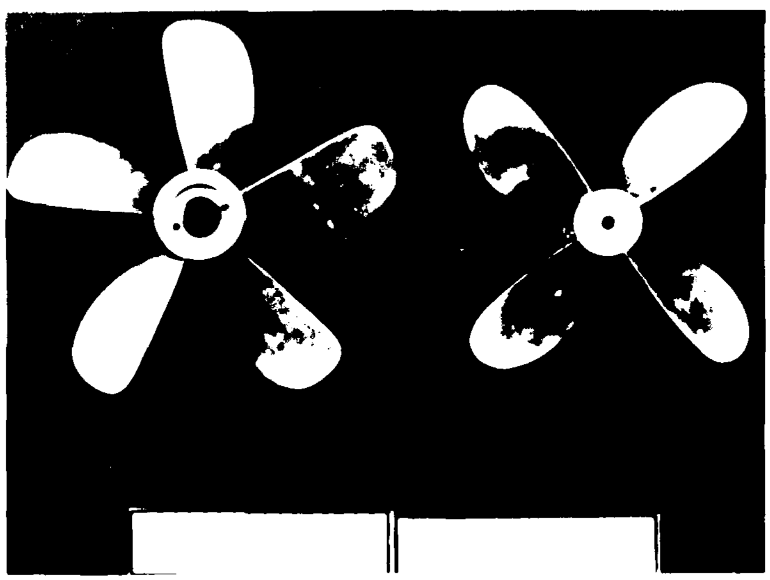


(PSD 2062 - 4 - 79)

Figure 2 - Photographs of Design Contrarotating Propellers 4731 and 4732 (DTNSRDC)



(PSD 2075 - 4 - 79)



(PSD 2071 - 4 - 79)

Figure 3 - Photographs of Design Contrarotating Propellers 9019 and 9020 (LIPS)

	PROP NO	LINEAR RATIO	DIA MODEL	DIA SHIP	PITCH MODEL AT 70 PCT	PITCH SHIP AT 70 PCT	PITCH RATIO AT 70 PCT	NUMBER OF BLADES	EXP AREA	E.A / D.A	M.W.R	PROJ. AREA	P.A / D.A	B.T.F	RAKE AWAY AT TIP	ROTATION	SHIP MODEL	SECTION LENGTH MODEL AT 70 PCT
INCHES MM	4731	25.200	10.000 254.00	252.000 6400.80	13.350 339.34	335.672 8551.47	1.335	5	35.201 23355.5	0.461	0.198	27.371 18045.9	0.355	0.035	0.000	L.H.	5362	2.037 51.74

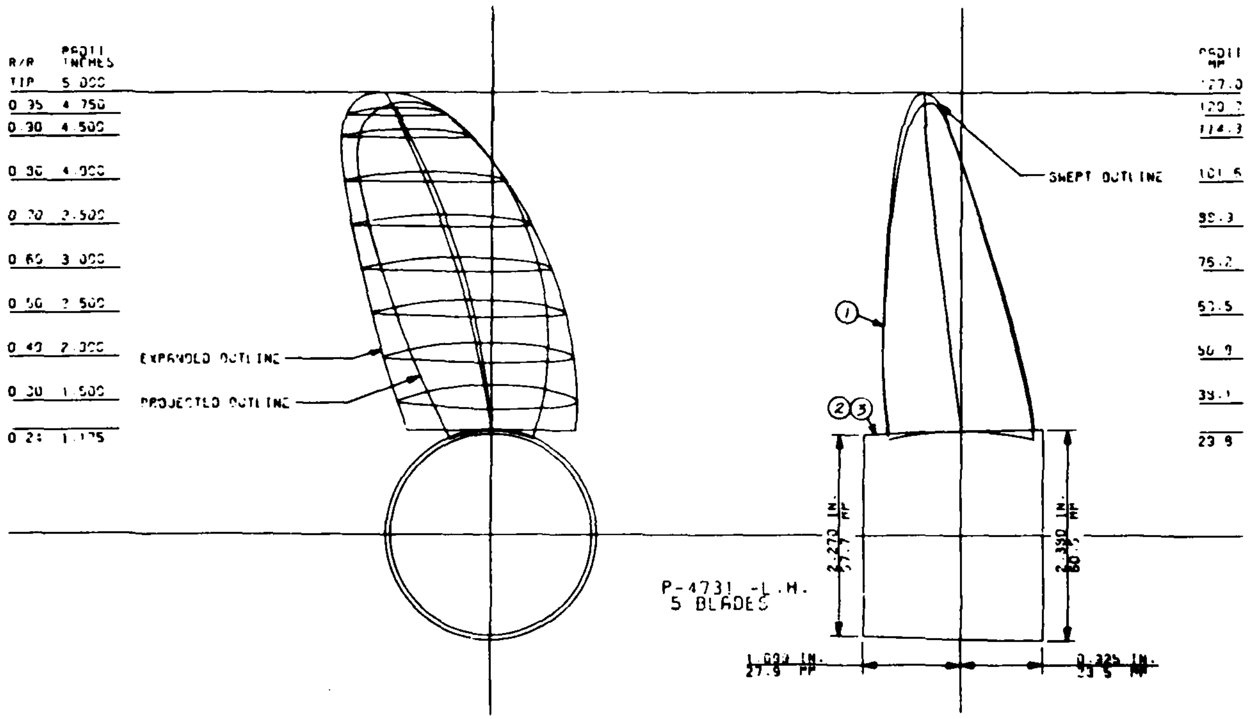


Figure 4 - Drawing of Propeller 4731 (DTNSRDC Forward)

	PROP NO	LINEAR RATIO	DIA MODEL	DIA SHIP	PITCH MODEL AT 70 PCT	PITCH SHIP AT 70 PCT	PITCH RATIO AT 70 PCT	NUMBER OF BLADES	EXP AREA	[illegible]	[illegible]	PROJ AREA	[illegible]	[illegible]	TOTAL SKEW AT TIP	ROTATION	SHIP RPM	SECTION LENGTH MODEL AT 70 PCT
INCHES MM	4732	25.200	9.524 241.90	240.000 6096.00	13.714 348.34	345.600 8778.24	1.440	4	27.172 17530.7	0.381	0.131	20.247 13062.4	0.284	0.035	0.000	R.H.	5352	1.940 49.28

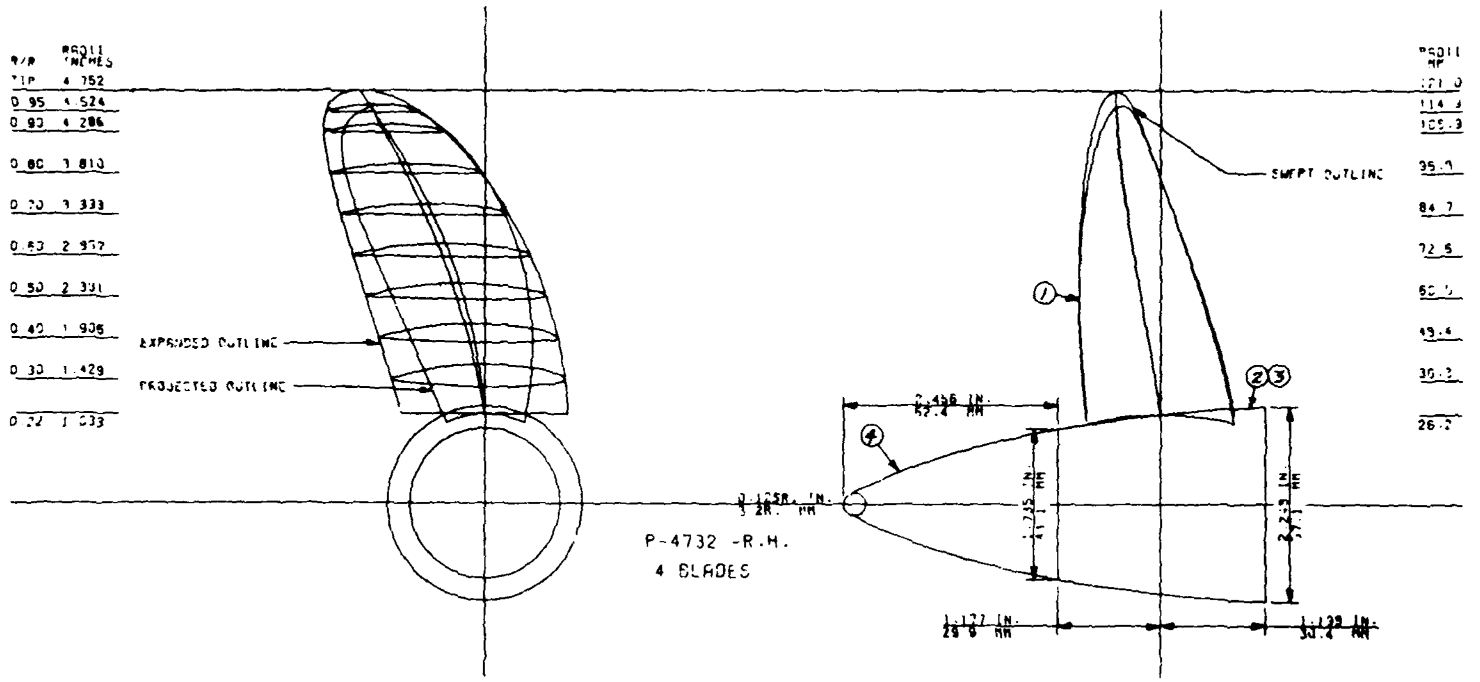


Figure 5 - Drawing of Propeller 4732 (DTNSRDC Aft)

	PROP. NO.	LINEAR RATIO	DIA. MODEL	DIA. SHIP	PITCH MODEL AT 70 PCT.	PITCH SHIP AT 70 PCT.	PITCH RATIO AT 70 PCT.	NUMBER OF BLADES	EXP. AREA	E.A./D.A.	M.W.R.	PROJ. AREA	P.A./D.A.	B.T.F.	RAKE ANGLE AT TIP	ROTATION	SHIP MODEL	SECTION LENGTH MODEL AT 70 PCT.
INCHES MM	9019	25.200	9.999 253.97	251.968 6399.99	12.744 323.69	321.141 8156.98	1.275	5	39.769 25657.7	0.507	0.208	31.864 20557.6	0.406	0.044	0.000	R.H.	5326	2.347 59.60

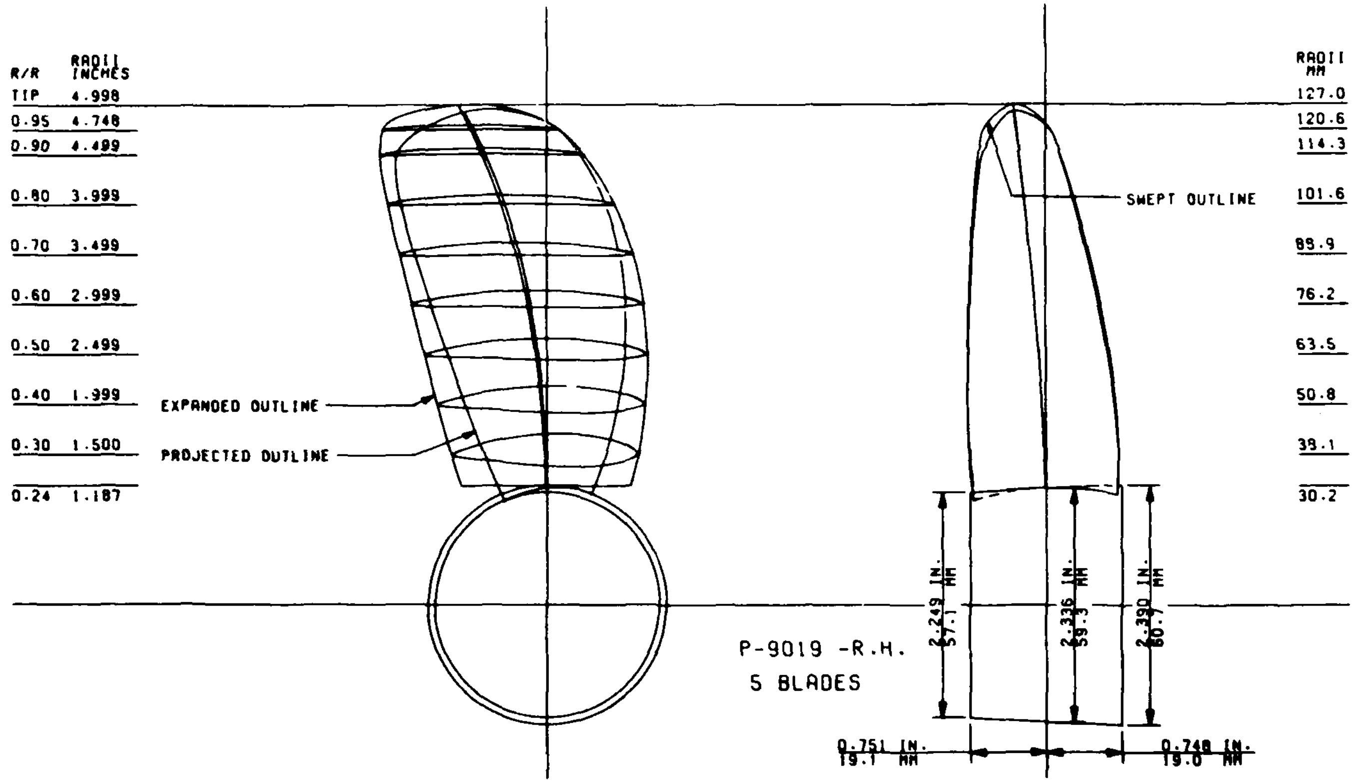


Figure 6 - Drawing of Propeller 9019 (LIPS Forward)

	PROP NO	LINEAR RATIO	DIA. MODEL	DIA. SHIP	PITCH MODEL AT 70 PCT	PITCH SHIP AT 70 PCT	PITCH RATIO AT 70 PCT.	NUMBER OF BLADES	EXP AREA	E.A./D.A.	M.W.R	PROJ AREA	P.A./D.A.	B.T.F.	RAKE ANGLE AT TIP	ROTATION	SHIP MODEL	SECTION LENGTH MODEL AT 70 PCT
INCHES MM	9020	25.200	9.518 241.75	239.842 6091.99	12.934 328.53	325.944 8278.98	1.359	4	31.206 20132.6	0.439	0.216	24.228 15630.7	0.341	0.042	0.000	L.H.	5362	2.290 58.17

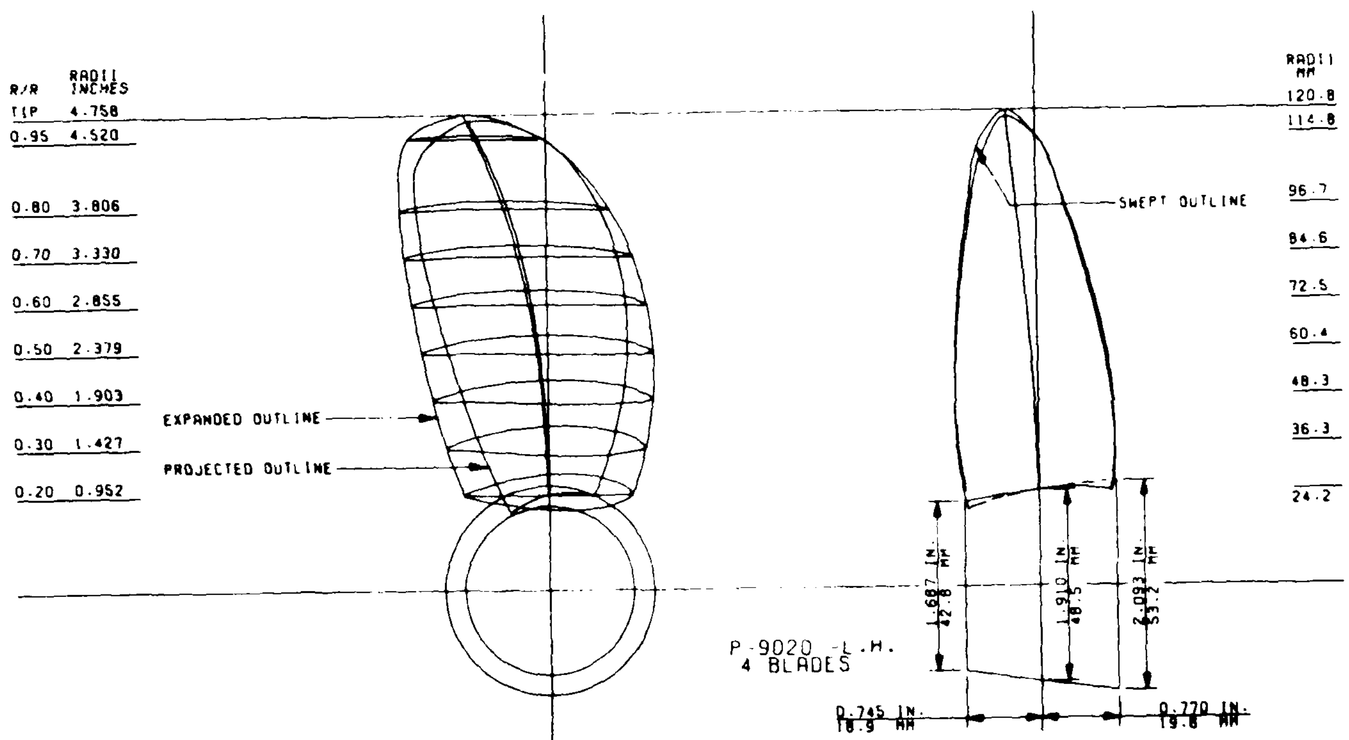
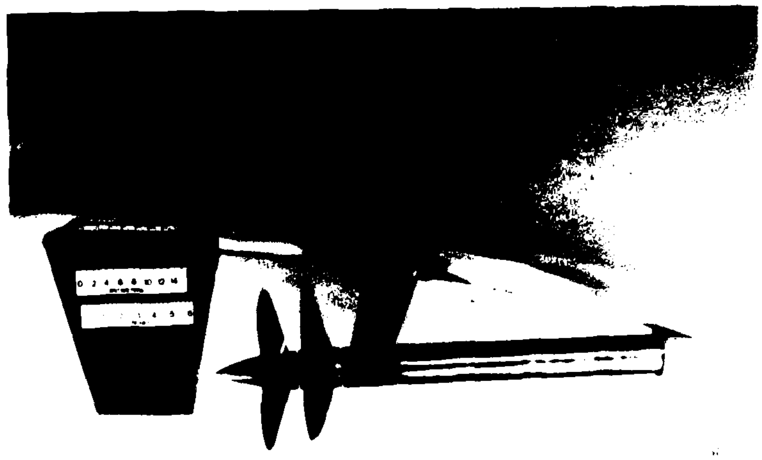


Figure 7 - Drawing of Propeller 9020 (LIPS Aft)



(PSD 2057 - 4 - 79)

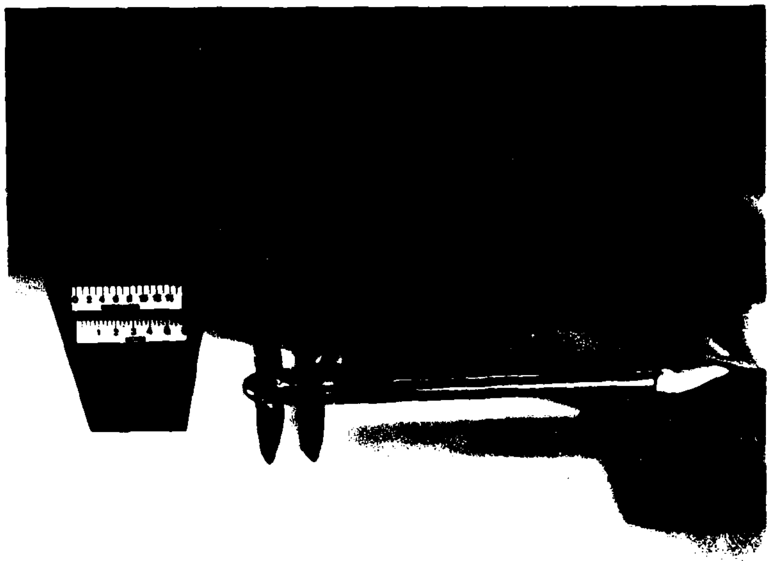
Figure 8 - DTNSRDC Design Contrarotating Propellers 4731 and 4732 on Model 5362 in their Design Position

(PSD 2054 - 4 - 79)

Figure 9 - LIPS Design Contrarotating Propellers 9019 and 9020 on Model 5362 in their Design Position

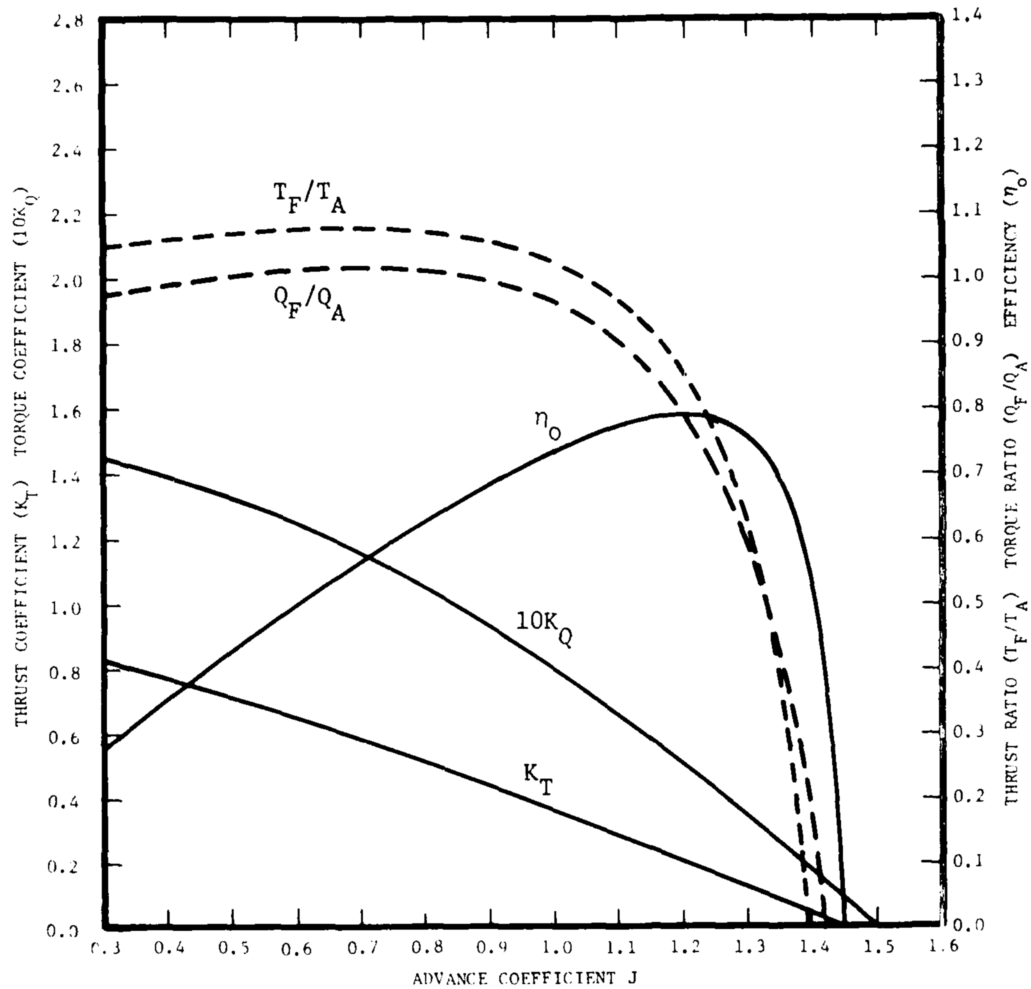
(PSD 2051 - 4 - 79)

Figure 10 - DTNSRDC Design Contrarotating Propellers 4731 and 4732 on Model 5362 in the LIPS Propeller Design Position



(PSD 2055 - 4 - 79)

Figure 11 - LIPS Design Contrarotating Propellers 9019 and 9020 on Model 5362 in the DTNSRDC Propeller Design Position

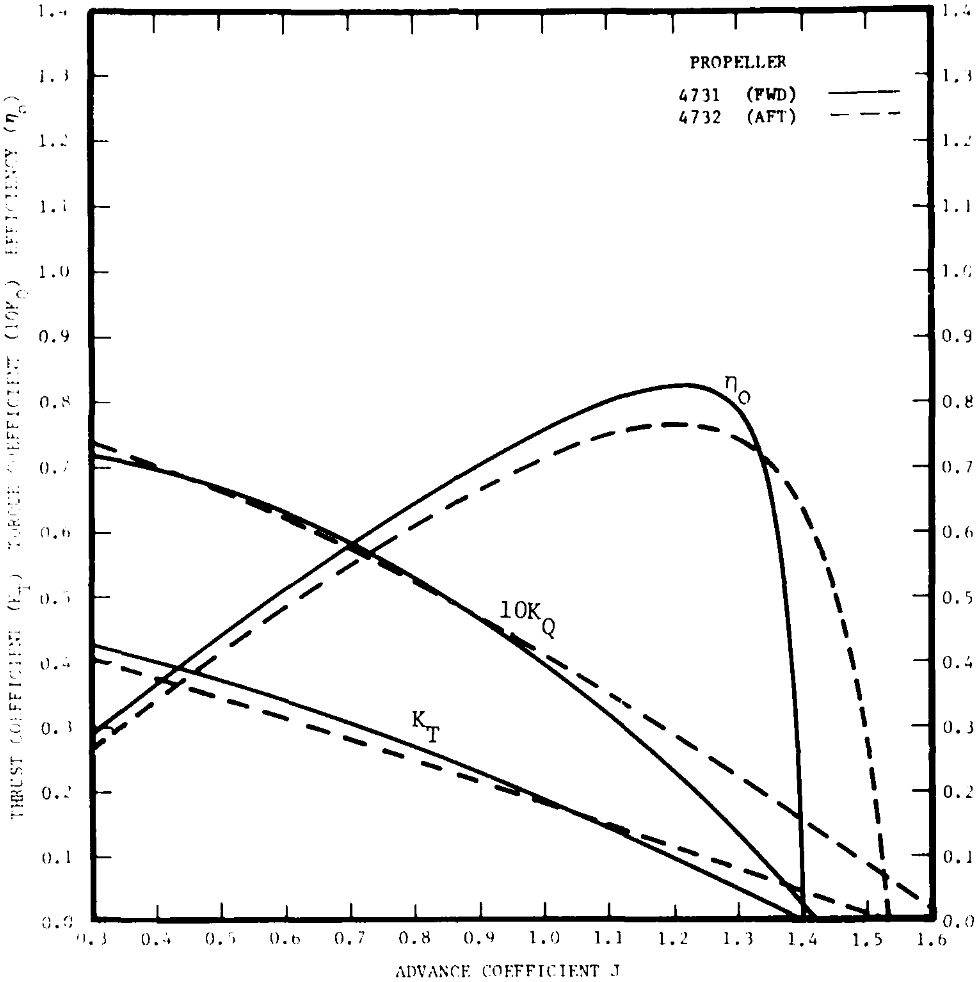


$$n_F/n_A = 1.0$$

$$J = \frac{V_A}{n_F D_F}, \qquad K_T = \frac{(T_F+T_A)}{\rho n_F^2 D_F^4}, \qquad K_Q = \frac{(Q_F \cdot n_F + Q_A \cdot n_A)}{\rho n_F^3 D_F^5},$$

$$\text{and} \quad \eta_o = \frac{K_T \cdot J}{K_Q \cdot 2\pi}$$

Figure 12 - Unit Open Water Curves for the DTNSRDC Design Contrarotating Propellers 4731 and 4732 from the November 1978 Open Water Experiments



$$n_F/n_A = 1.0$$

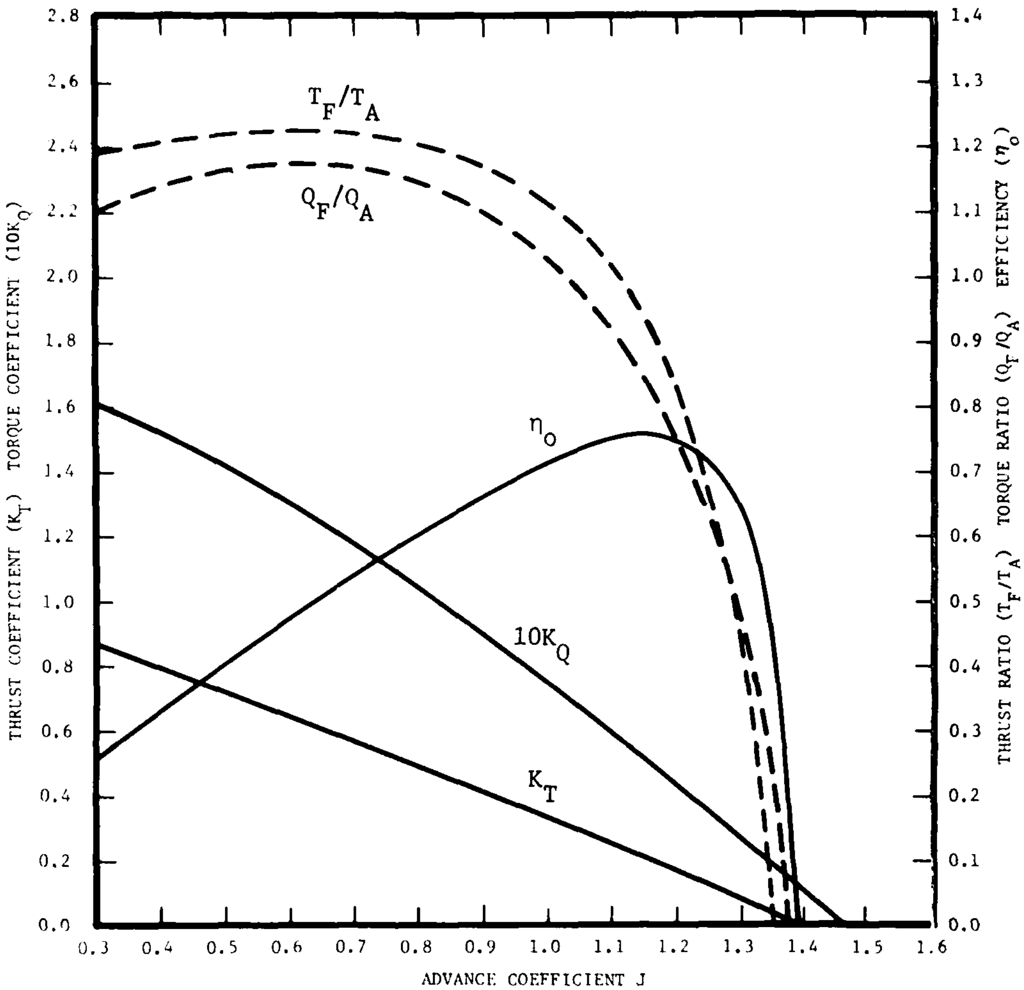
Forward Propeller

Aft Propeller

$$K_T = \frac{T_F}{\rho n_F^2 D_F^4} \qquad J = \frac{V_A}{n_F D_F} \qquad K_T = \frac{T_A}{\rho n_F^2 D_F^4}$$

$$K_Q = \frac{Q_F}{\rho n_F^2 D_F^5} \qquad \eta_o = \frac{K_T \cdot J}{K_Q \cdot 2\pi} \qquad K_Q = \frac{Q_A \cdot n_A}{\rho n_F^3 D_F^5}$$

Figure 13 - Open Water Curves for the DTNSRDC Design Contrarotating Propellers 4731 and 4732 Operating as a Pair from the November 1978 Open Water Experiments

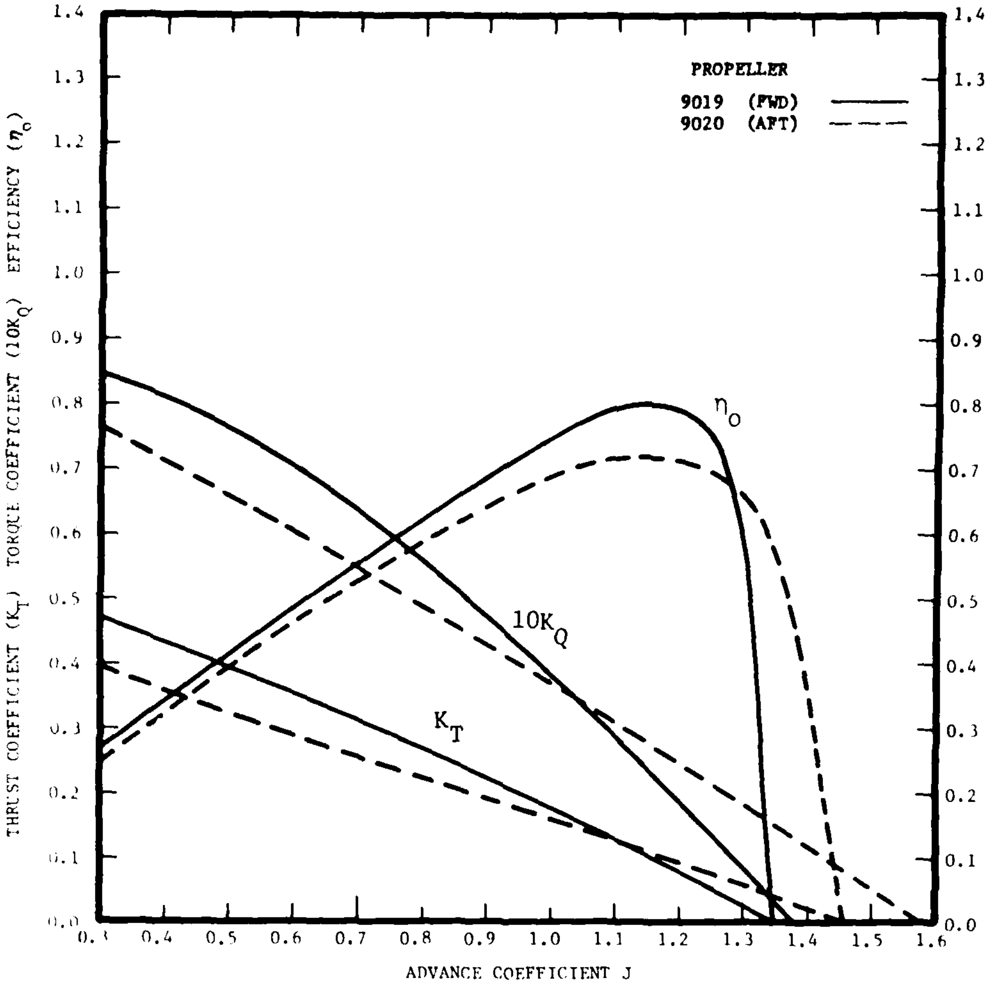


$$n_F/n_A = 1.0$$

$$J = \frac{V_A}{n_F D_F}, \qquad K_T = \frac{(T_F + T_A)}{\rho n_F^2 D_F^4}, \qquad K_Q = \frac{(Q_F \cdot n_F + Q_A \cdot n_A)}{\rho n_F^3 D_F^5},$$

$$\text{and} \quad \eta_o = \frac{K_T \cdot J}{K_Q \cdot 2\pi}$$

Figure 14 - Unit Open Water Curves for the LIPS Design Contrarotating Propellers 9019 and 9020 from the November 1978 Open Water Experiments



$$n_F/n_A = 1.0$$

Forward Propeller

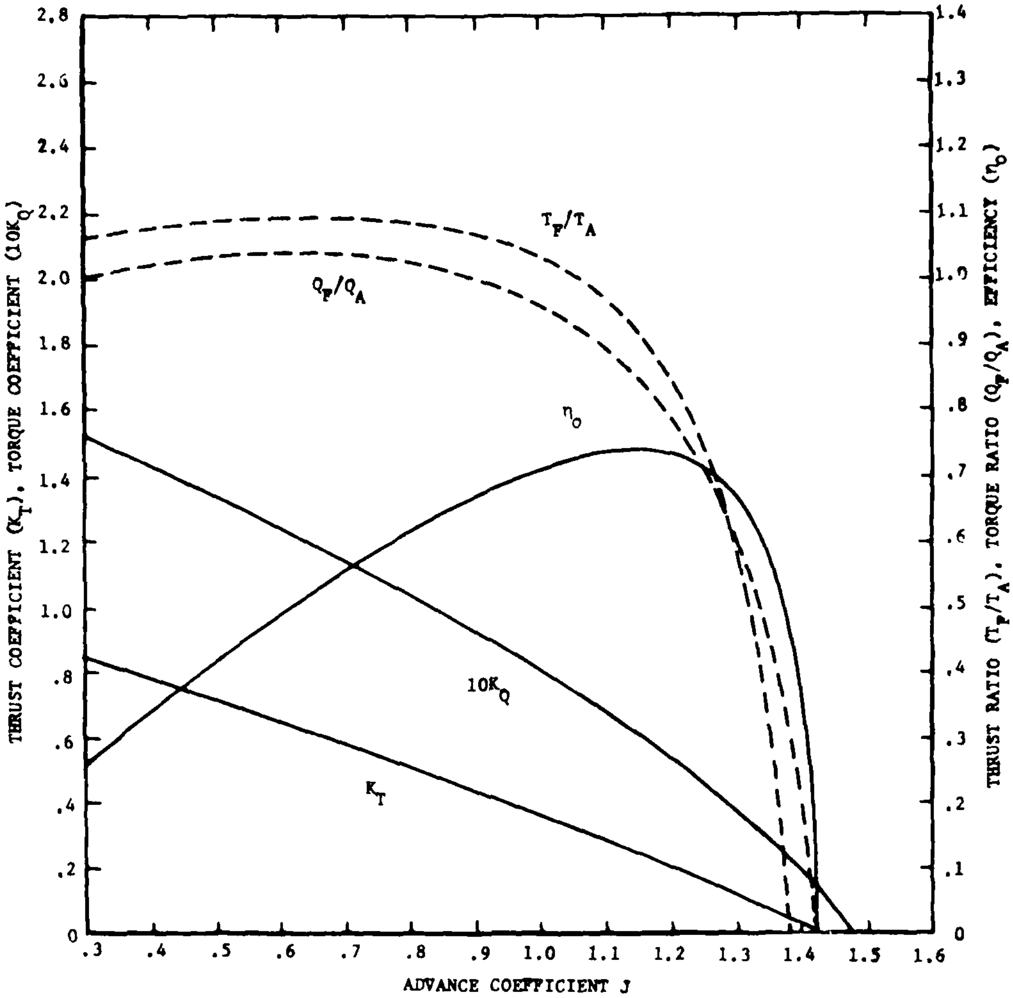
$$K_T = \frac{T_F}{\rho n_F^2 D_F^4} \qquad K_Q = \frac{Q_F}{\rho n_F^2 D_F^5}$$

$$J = \frac{V_A}{n_F D_F} \qquad \eta_o = \frac{K_T \cdot J}{K_Q \cdot 2\pi}$$

Aft Propeller

$$K_T = \frac{T_A}{\rho n_F^2 D_F^4} \qquad K_Q = \frac{Q_A \cdot n_A}{\rho n_F^3 D_F^5}$$

Figure 15 - Open Water Curves for the LIPS Design Contrarotating Propellers 9019 and 9020 Operating as a Pair frcm the November 1978 Open Water Experiments

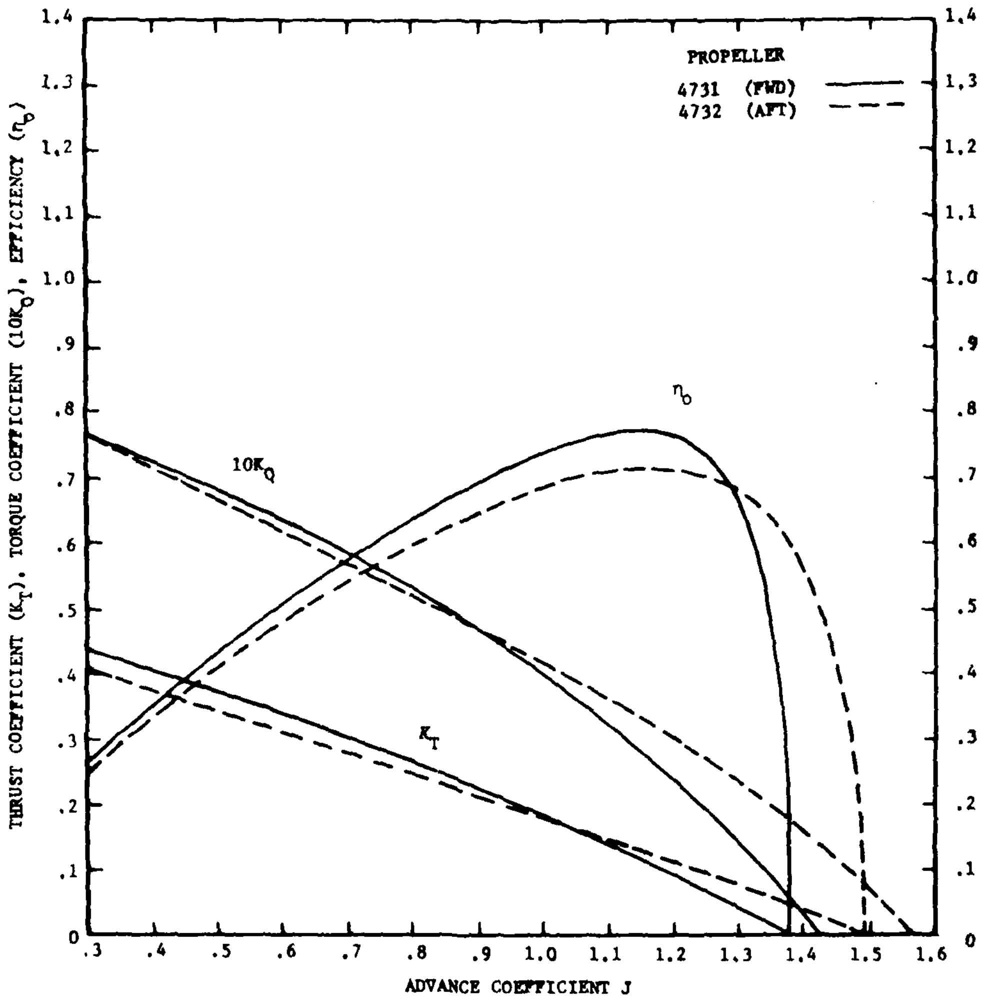


$$n_F/n_A = 1.0$$

$$J = \frac{V_A}{n_F D_F}, \qquad K_T = \frac{(T_F+T_A)}{\rho n_F{}^2 D_F{}^4}, \qquad K_Q = \frac{(Q_F \cdot n_F + Q_A \cdot n_A)}{\rho n_F{}^3 D_F{}^5},$$

$$\text{and} \quad \eta_o = \frac{K_T \cdot J}{K_Q \cdot 2\pi}$$

Figure 16 - Unit Open Water Curves for the DTNSRDC Design Contrarotating Propellers 4731 and 4732 from the April 1979 Open Water Experiments



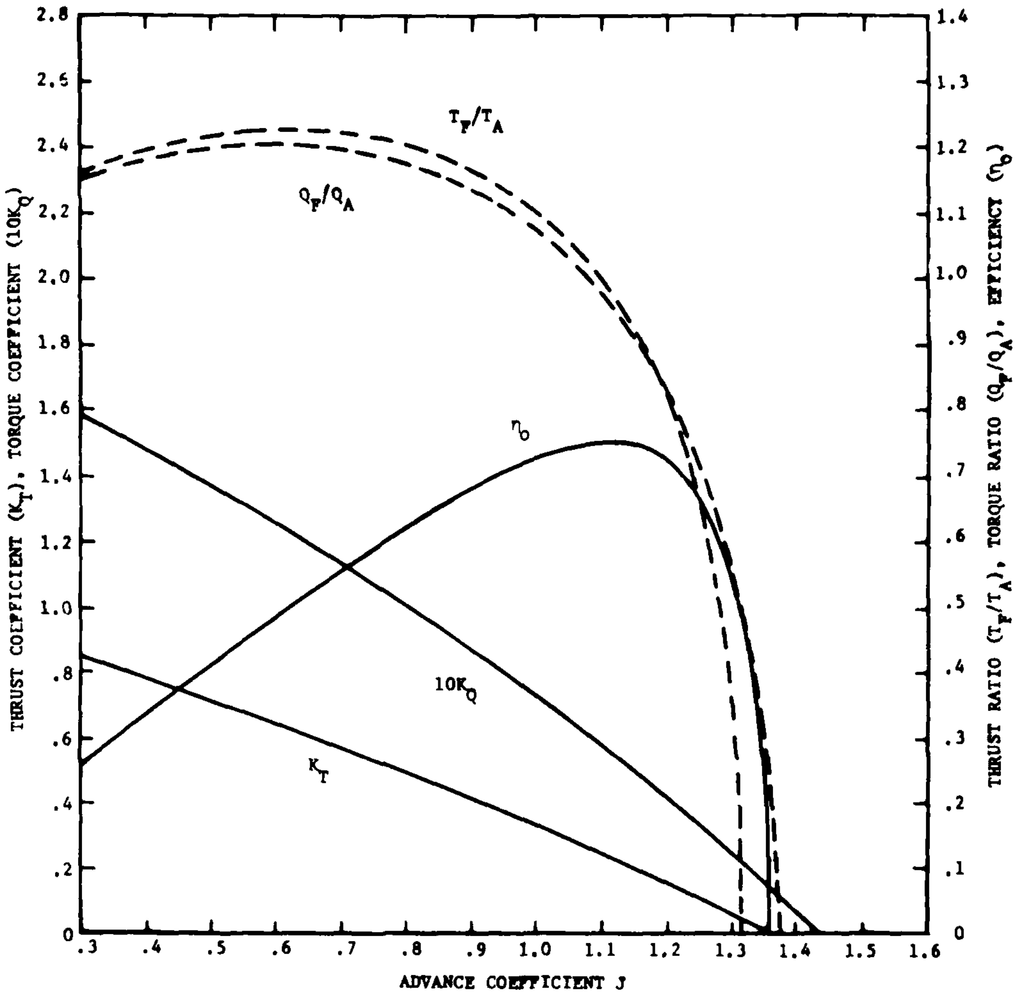
$$n_F/n_A = 1.0$$

Forward Propeller | **Aft Propeller**

$$K_T = \frac{T_F}{\rho n_F^2 D_F^4} \qquad J = \frac{V_A}{n_F D_F} \qquad K_T = \frac{T_A}{\rho n_F^2 D_F^4}$$

$$K_Q = \frac{Q_F}{\rho n_F^2 D_F^5} \qquad \eta_o = \frac{K_T \cdot J}{K_Q \cdot 2\pi} \qquad K_Q = \frac{Q_A \cdot n_A}{\rho n_F^3 D_F^5}$$

Figure 17 - Open Water Curves for the DTNSRDC Design Contrarotating Propellers 4731 and 4732 Operating as a Pair from the April 1979 Open Water Experiments

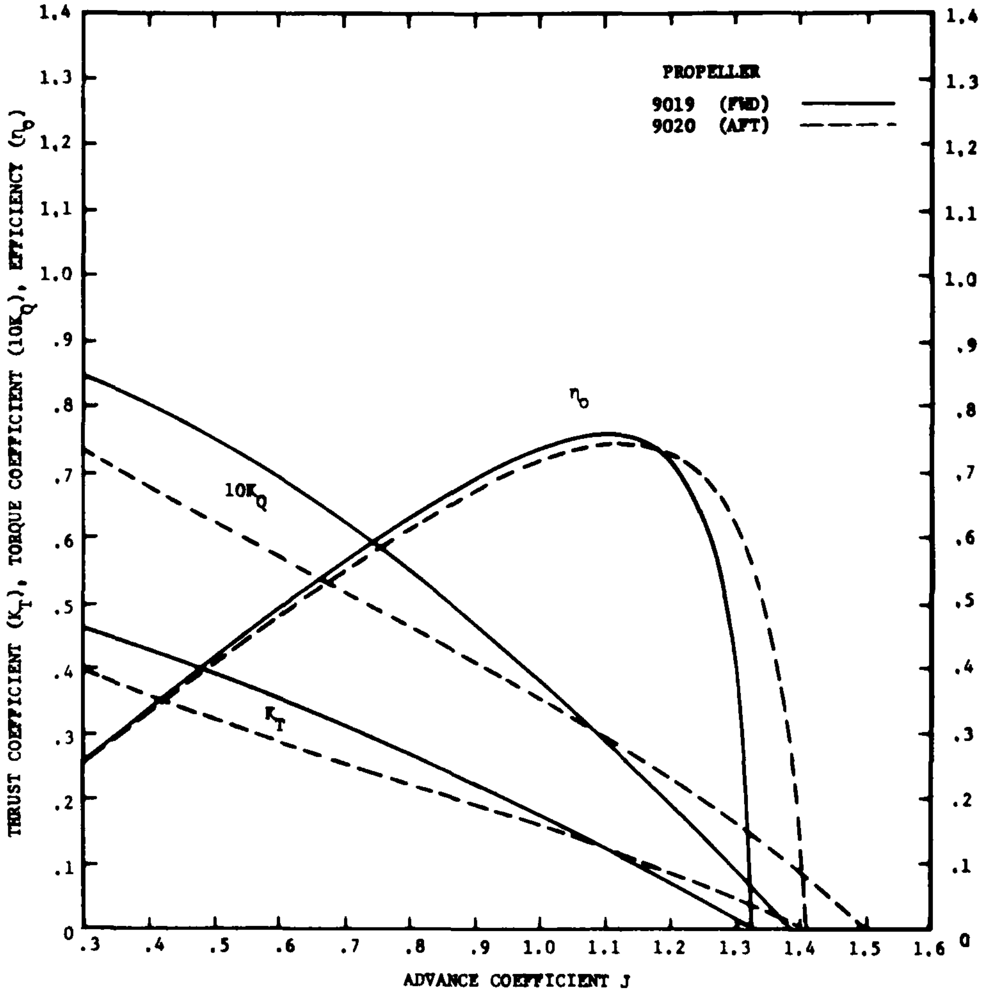


$$n_F/n_A = 1.0$$

$$J = \frac{V_A}{n_F D_F} , \qquad K_T = \frac{(T_F+T_A)}{\rho n_F^2 D_F^4} , \qquad K_Q = \frac{(Q_F \cdot n_F + Q_A \cdot n_A)}{\rho n_F^3 D_F^5} ,$$

$$\text{and} \quad \eta_o = \frac{K_T \cdot J}{K_Q \cdot 2\pi}$$

Figure 18 - Unit Open Water Curves for the LIPS Design Contrarotating Propellers 9019 and 9020 from the April 1979 Open Water Experiments



$$n_F/n_A = 1.0$$

Forward Propeller

$$K_T = \frac{T_F}{\rho n_F^2 D_F^4}$$

$$K_Q = \frac{Q_F}{\rho n_F^2 D_F^5}$$

$$J = \frac{V_A}{n_F D_F}$$

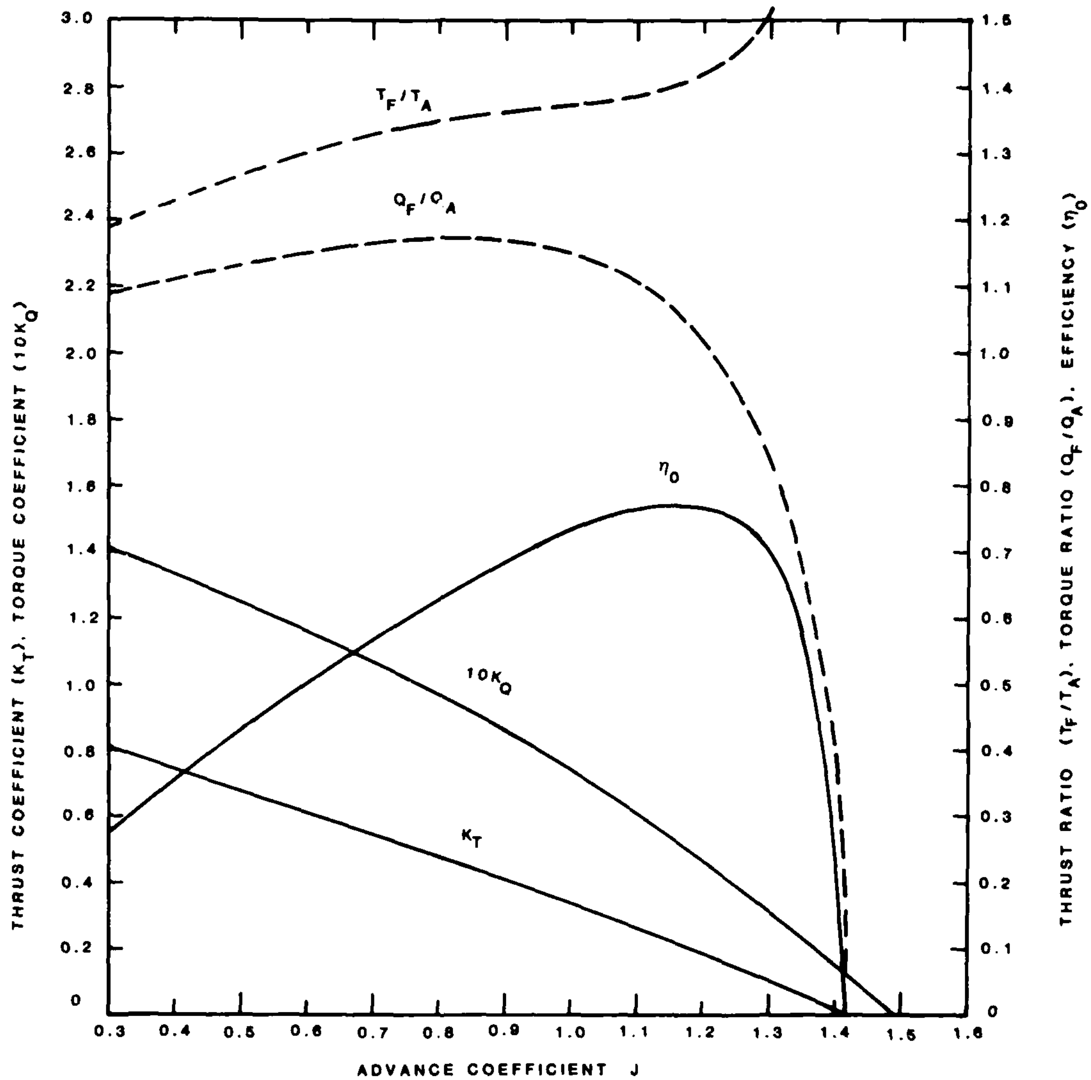
$$\eta_o = \frac{K_T \cdot J}{K_Q \cdot 2\pi}$$

Aft Propeller

$$K_T = \frac{T_A}{\rho n_F^2 D_F^4}$$

$$K_Q = \frac{Q_A \cdot n_A}{\rho n_F^3 D_F^5}$$

Figure 19 - Open Water Curves for the LIPS Design Contrarotating Propellers 9019 and 9020 Operating as a Pair from the April 1979 Open Water Experiments

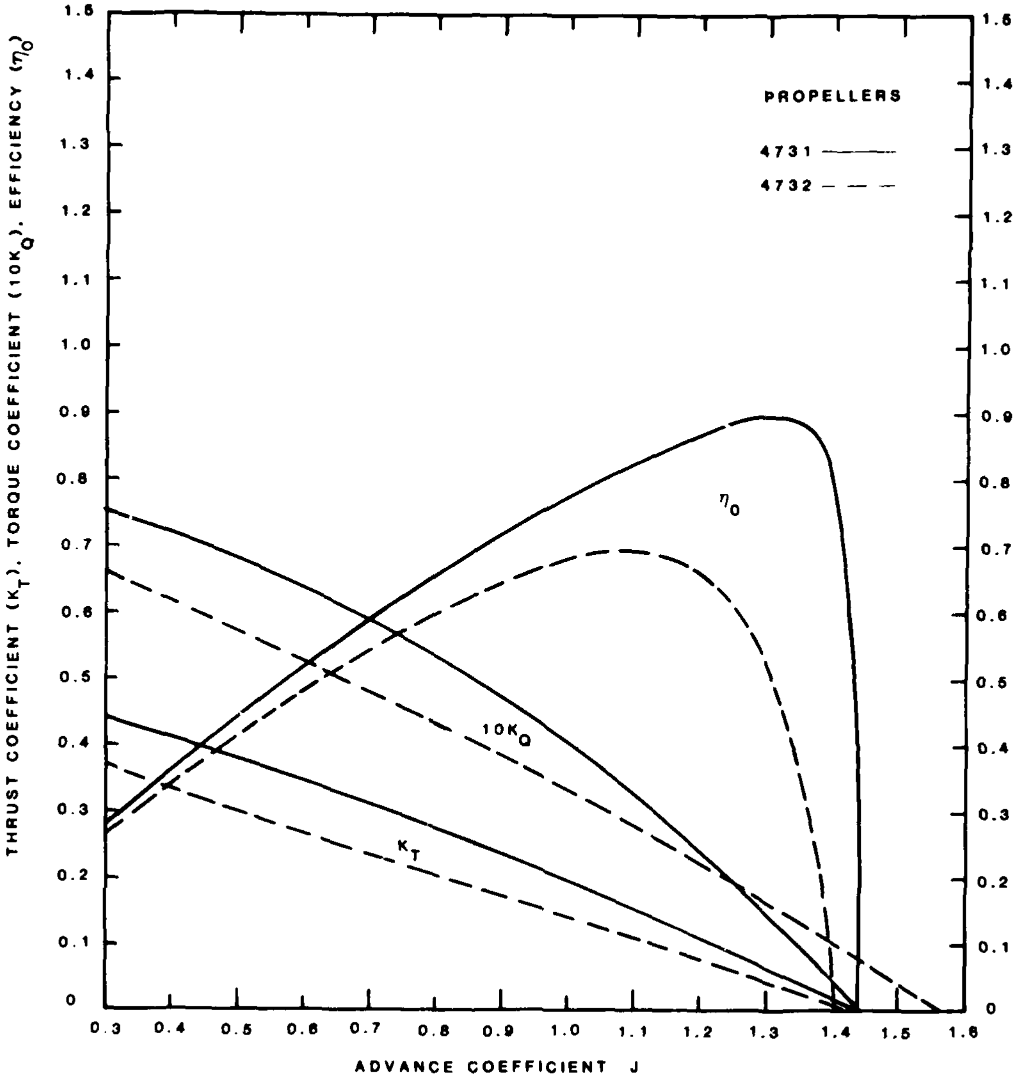


$$n_F/n_A = 1.05$$

$$J = \frac{V_A}{n_F D_F}, \qquad K_T = \frac{(T_F+T_A)}{\rho n_F^2 D_F^4}, \qquad K_Q = \frac{(Q_F \cdot n_F + Q_A \cdot n_A)}{\rho n_F^3 D_F^5},$$

$$\text{and} \quad \eta_o = \frac{K_T \cdot J}{K_Q \cdot 2\pi}$$

Figure 20 - Unit Open Water Curves for the DTNSRDC Design Contrarotating Propellers 4731 and 4732 from the May 1980 Open Water Experiments at an RPM Ratio of 1.05.



$$n_F/n_A = 1.05$$

Forward Propeller | **Aft Propeller**

$$K_T = \frac{T_F}{\rho n_F^2 D_F^4} \qquad J = \frac{V_A}{n_F D_F} \qquad K_T = \frac{T_A}{\rho n_F^2 D_F^4}$$

$$K_Q = \frac{Q_F}{\rho n_F^2 D_F^5} \qquad \eta_0 = \frac{K_T \cdot J}{K_Q \cdot 2\pi} \qquad K_Q = \frac{Q_A \cdot n_A}{\rho n_F^3 D_F^5}$$

Figure 21 - Open Water Curves for the DTNSRDC Design Contrarotating Propellers 4731 and 4732 Operating as a Pair from the May 1980 Open Water Experiments at an RPM Ratio of 1.05

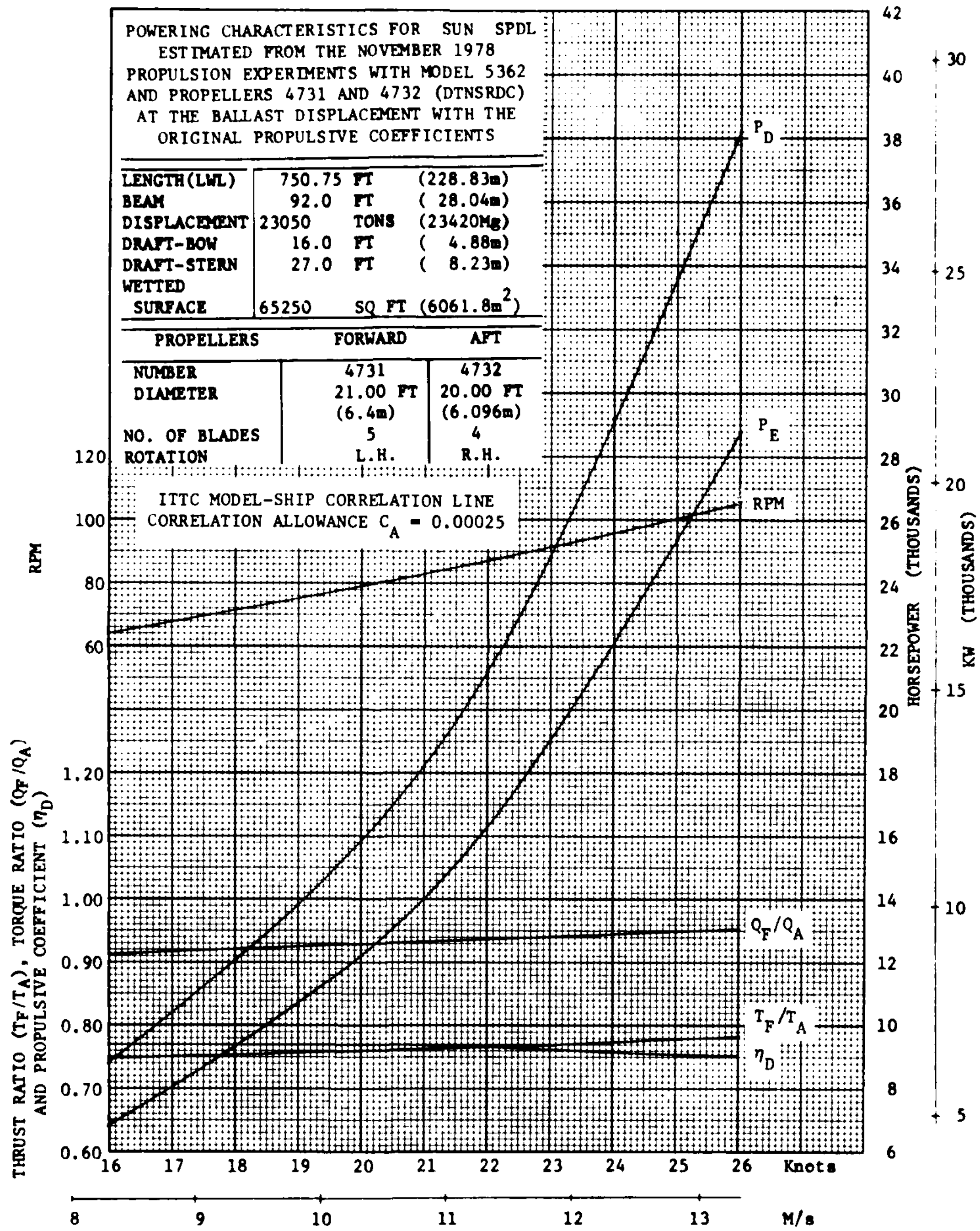


Figure 22 - Ballast Displacement Powering Characteristics for the Stretched PONCE DE LEON (SPDL) Class RO/RO Ship with the DTNSRDC Design Propellers From the November 1978 Propulsion Experiments with the Original Propulsive Coefficients (Model 5362 with Propellers DTNSRDC 4731 and 4732)

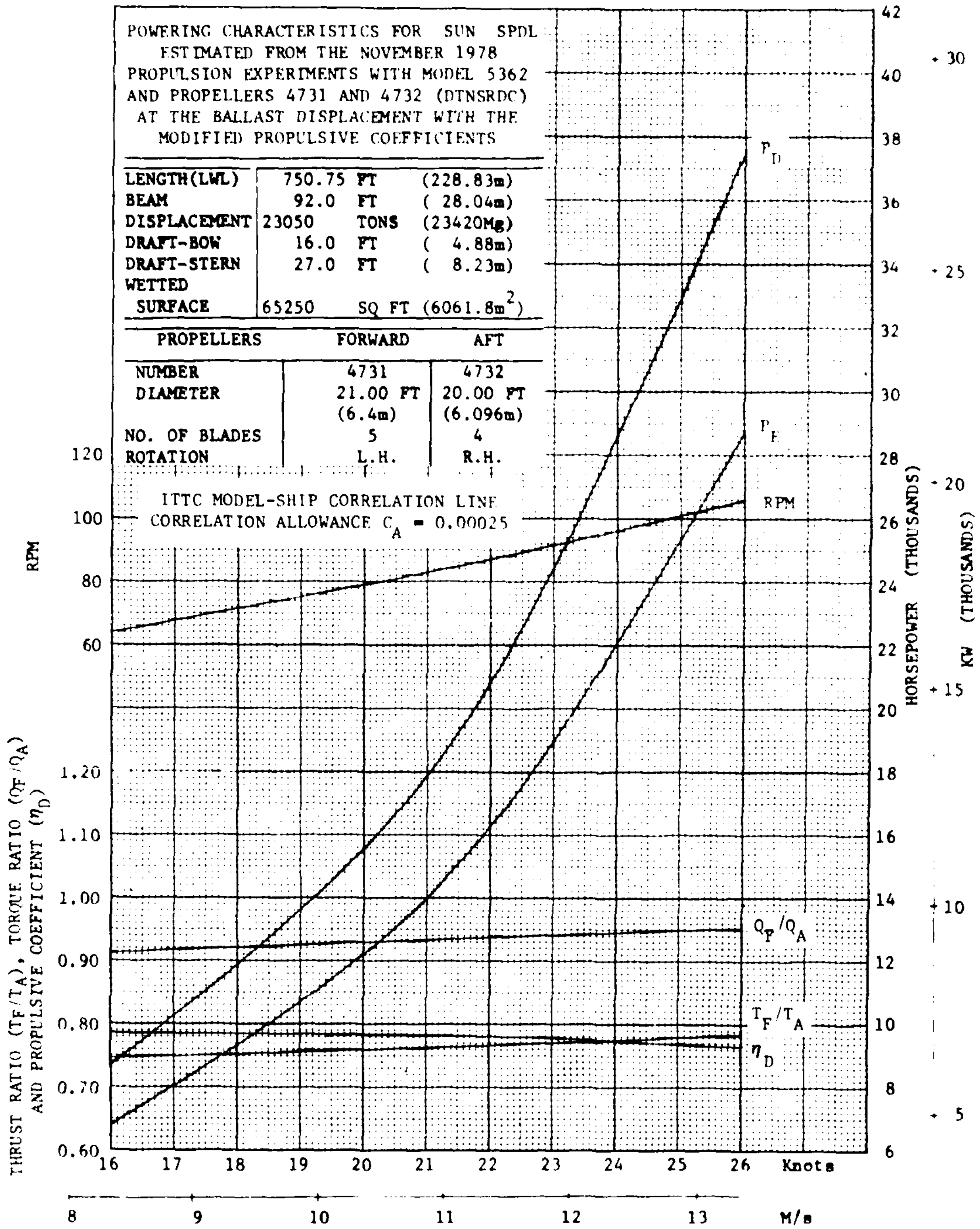


Figure 23 - Ballast Displacement Powering Characteristics for the Stretched PONCE DE LEON (SPDL) Class RO/RO Ship with the DTNSRDC Design Propellers From the November 1978 Propulsion Experiments with the Corrected Propulsive Coefficients (Model 5362 with Propellers DTNSRDC 4731 and 4732)

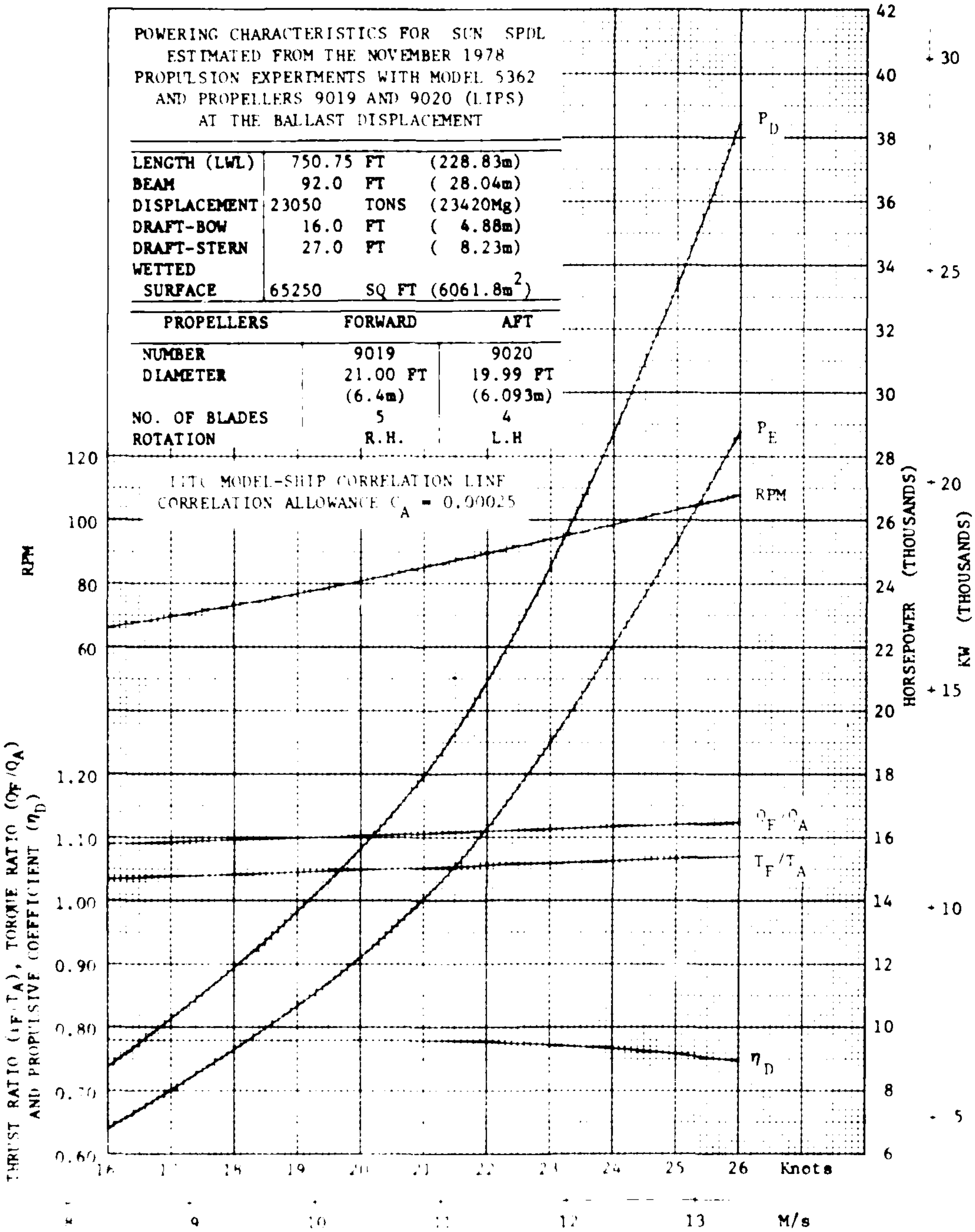


Figure 24 Ballast Displacement Powering Characteristics for the Stretched PONCE DE LEON (CF III) Class RO/RO Ship with the LIPS Design Propellers From the November 1978 Propulsion Experiments (Model 5362 with Propellers LIPS 9019 and 9020)

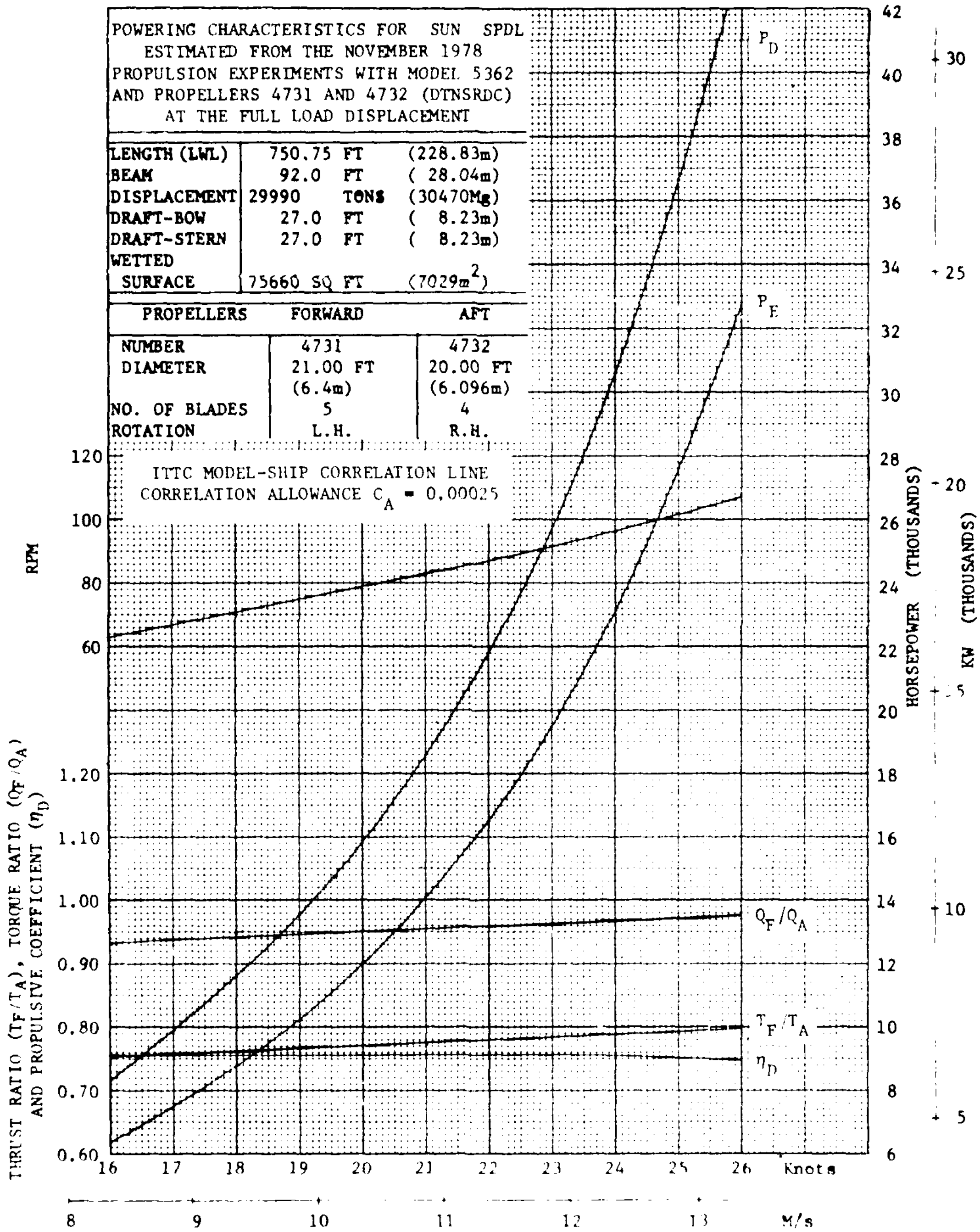


Figure 25 - Full Load Displacement Powering Characteristics for the Stretched PONCE DE LEON (SPDL) Class RO/RO Ship with the DTNSRDC Design Propellers From the November 1978 Propulsion experiments (Model 5362 with Propellers DTNSRDC 4731 and 4732)

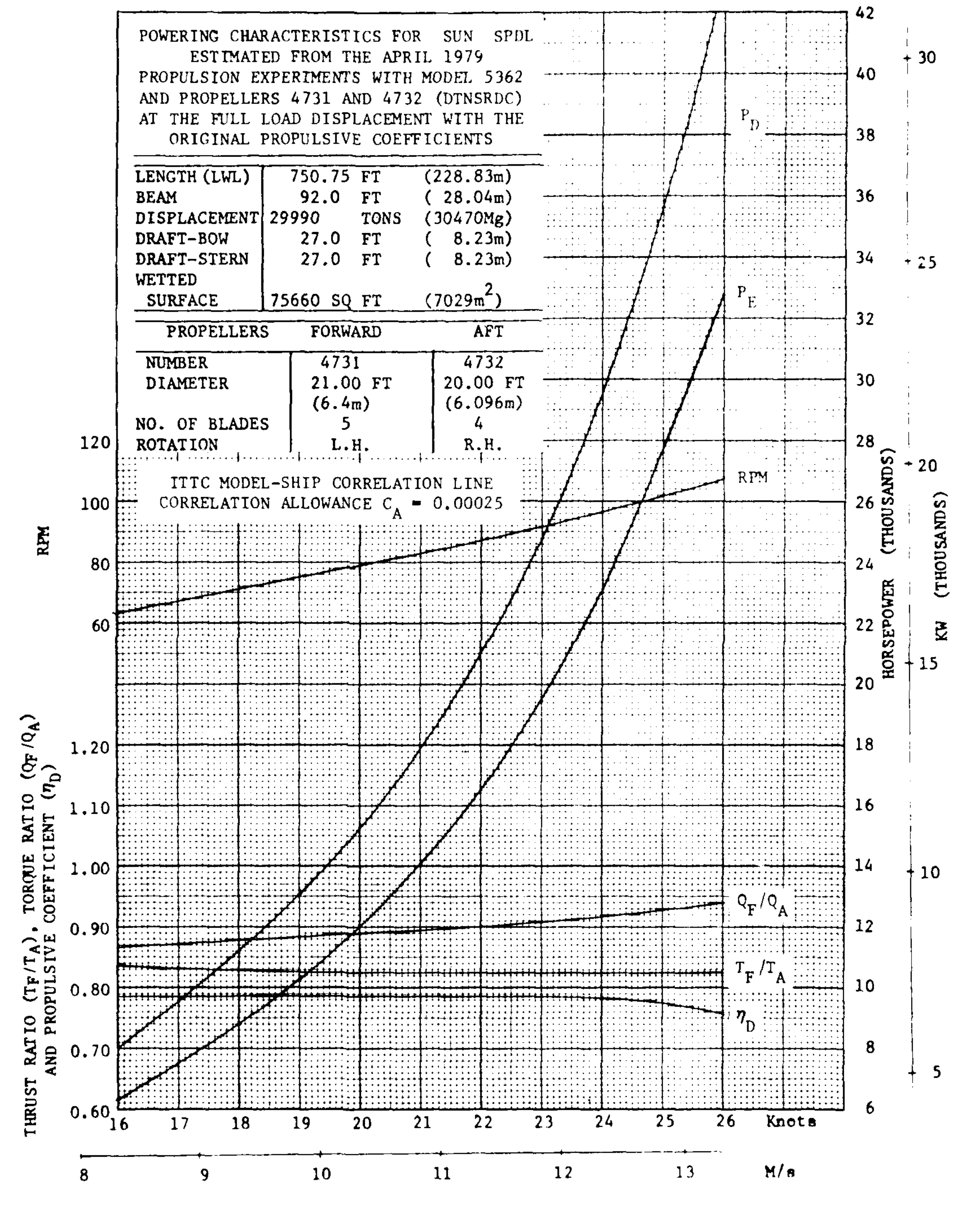


Figure 26 - Full Load Displacement Powering Characteristics for the Stretched PONCE DE LEON (SPDL) Class RO/RO Ship with the DTNSRDC Design Propellers From the April 1979 Propulsion Experiments with the Original Propulsive Coefficients (Model 5362 with Propellers DTNSRDC 4731 and 4732)

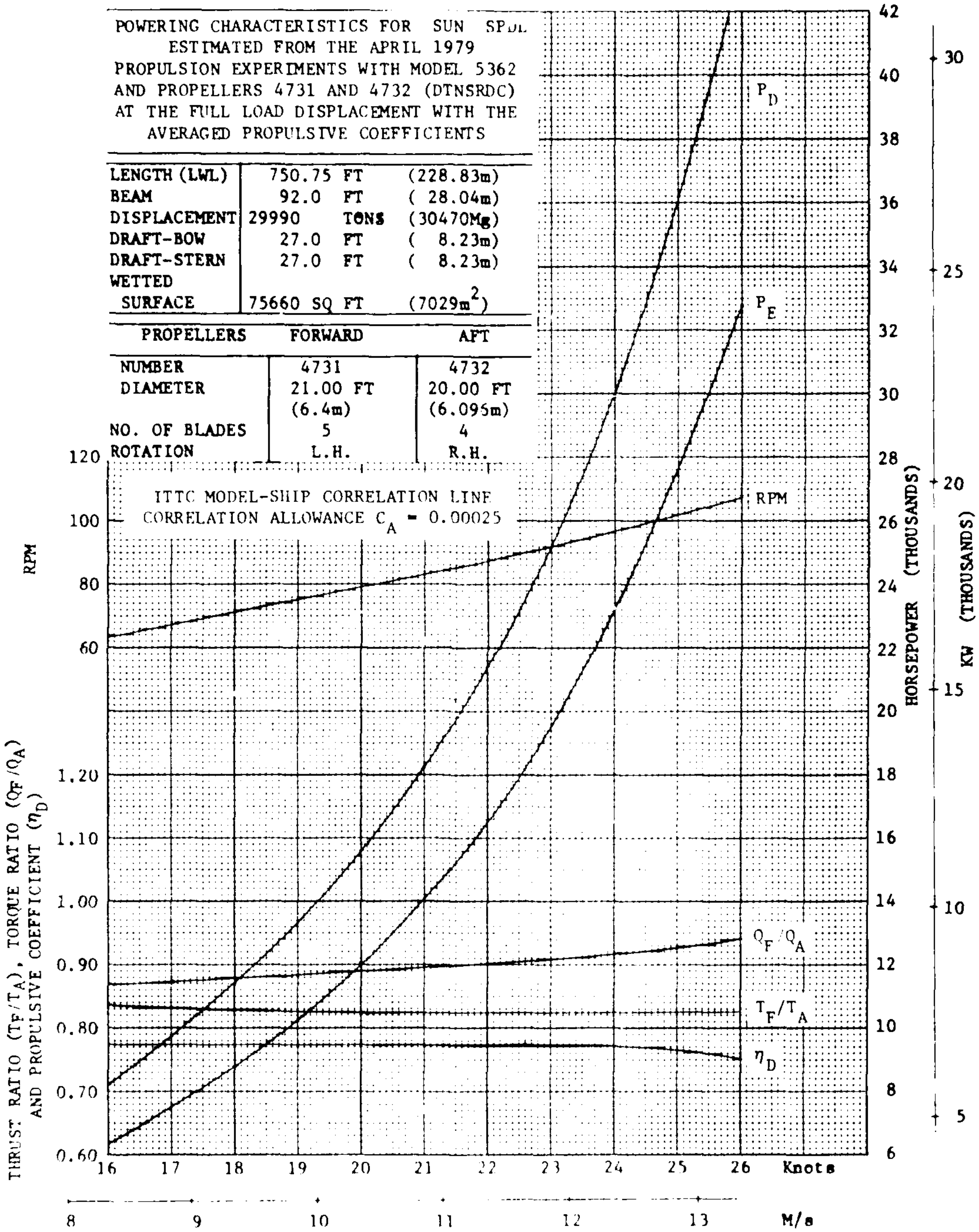


Figure 27 - Full Load Displacement Powering Characteristics for the Stretched PONCE DE LEON (SPDL) Class RO/RO Ship with the DTNSRDC Design Propellers From the April 1979 Propulsion experiments with the Averaged Propulsive Coefficients (Model 5362 with Propellers DTNSRDC 4731 and 4732)

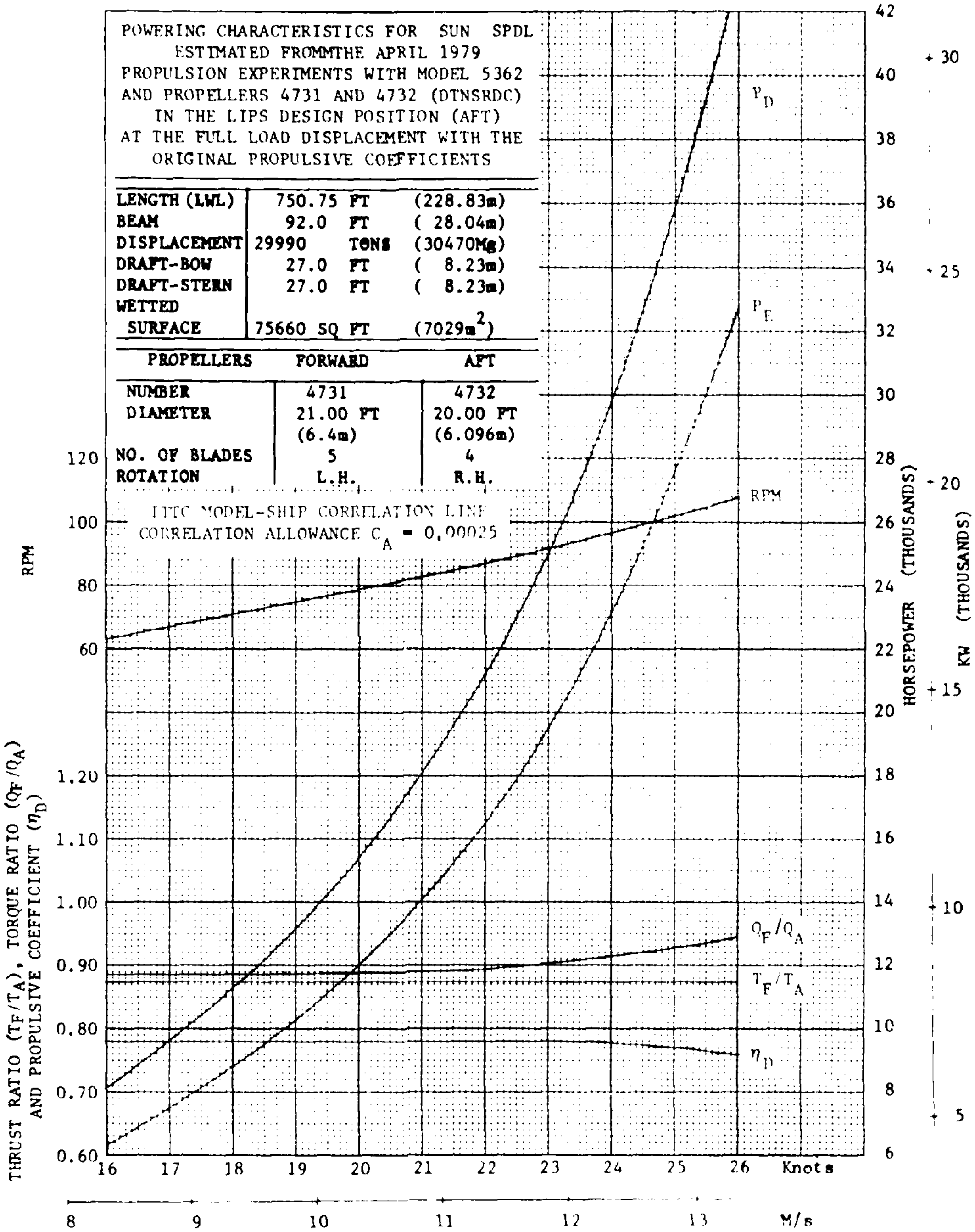


Figure 28 - Full Load Displacement Powering Characteristics for the Stretched PONCE DE LEON (SPDL) Class RO/RO Ship with the DTNSRDC Design Propellers in the LIPS Propeller Design Position (aft) From the April 1979 Propulsion Experiments with the Original Propulsive Coefficients (Model 5362 with Propellers DTNSRDC 4731 and 4732)

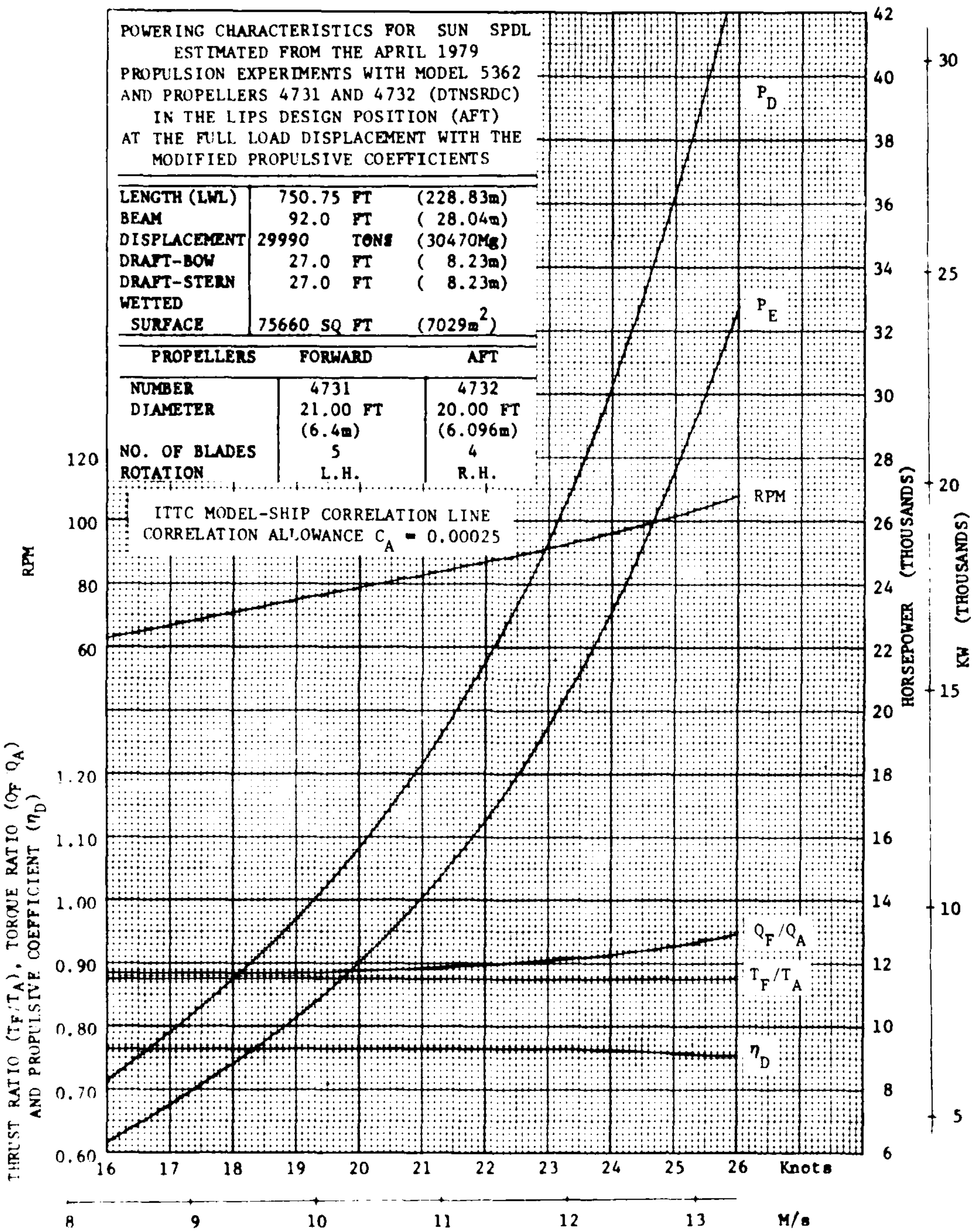


Figure 20 - Full Load Displacement Powering Characteristics for the Stretched PONCE DE LEON (SPDL) Class RO/RO Ship with the DTNSRDC Design Propellers in the LIPS Propeller Design Position (aft) From the April 1979 Propulsion Experiments with the Corrected Propulsive Coefficients (Model 5362 with Propellers DTNSRDC 4731 and 4732)

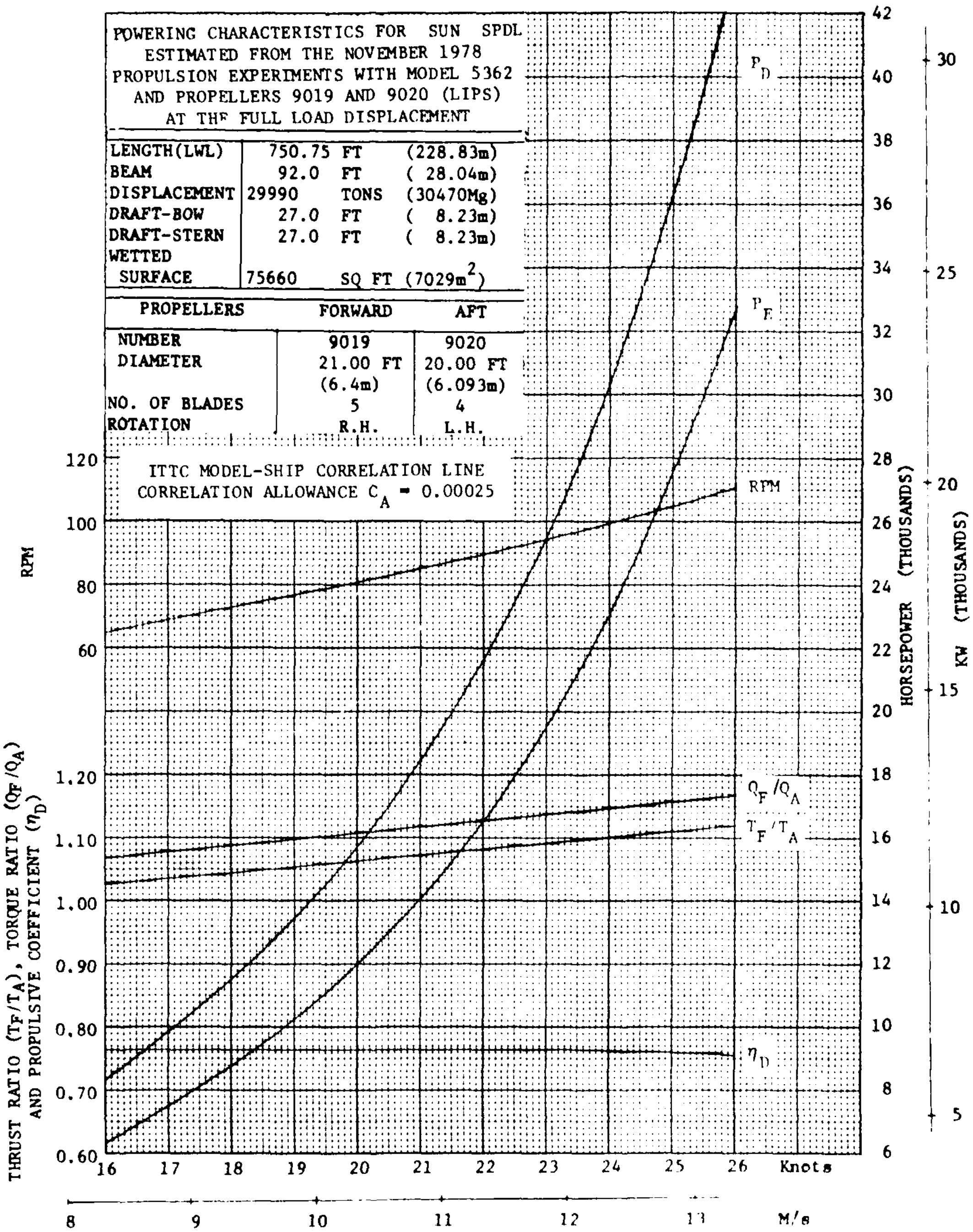


Figure 30 - Full Load Displacement Powering Characteristics for the Stretched PONCE DE LEON (SPDL) Class RO/RO Ship with the LIPS Design Propellers From the November 1978 Propulsion Experiments (Model 5362 with Propellers LIPS 9019 and 9020)

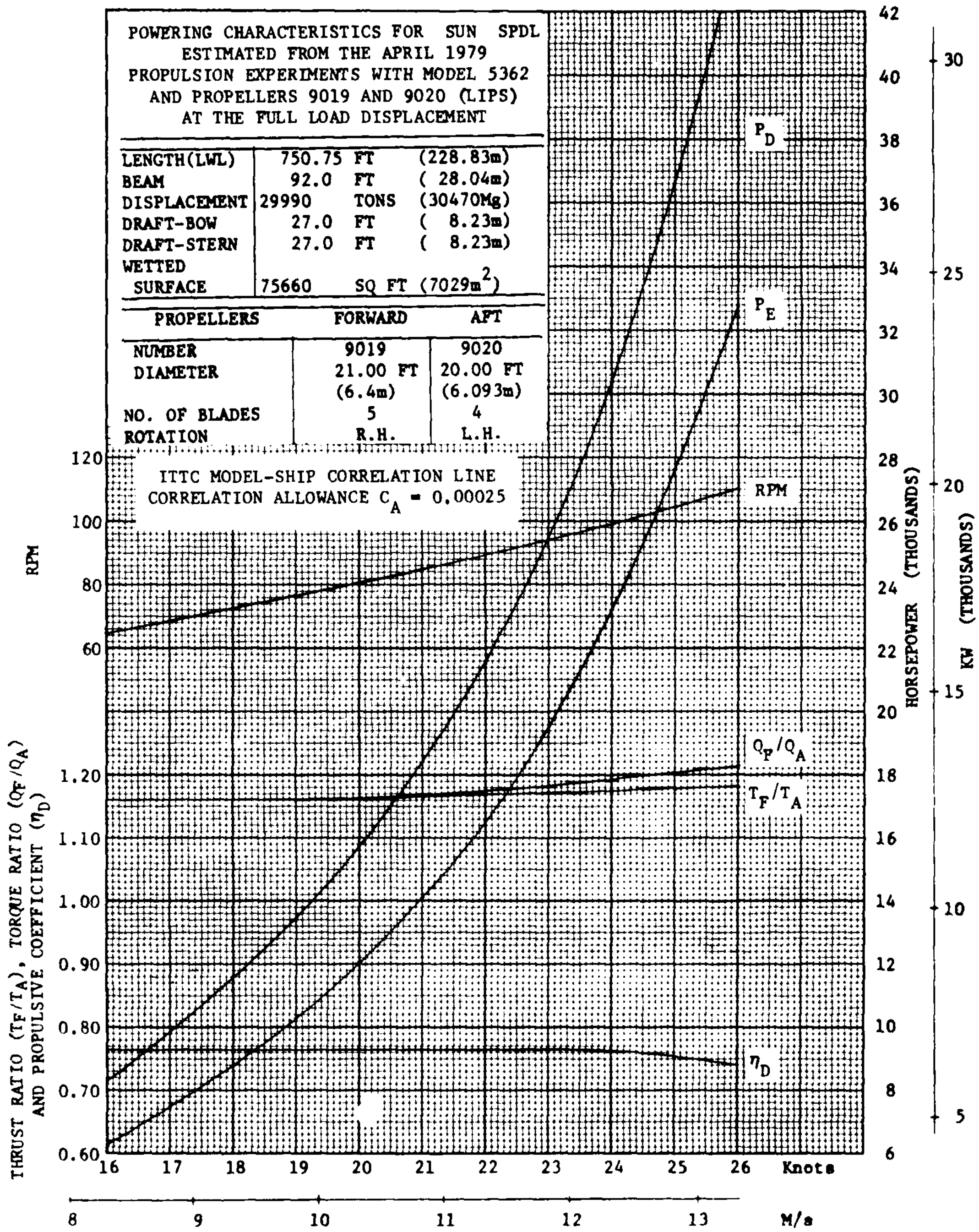


Figure 31 - Full Load Displacement Powering Characteristics for the Stretched PONCE DE LEON (SPDL) Class RO/RO Ship with the LIPS Design Propellers From the April 1979 Propulsion Experiments (Model 5362 with Propellers LIPS 9019 and 9020)

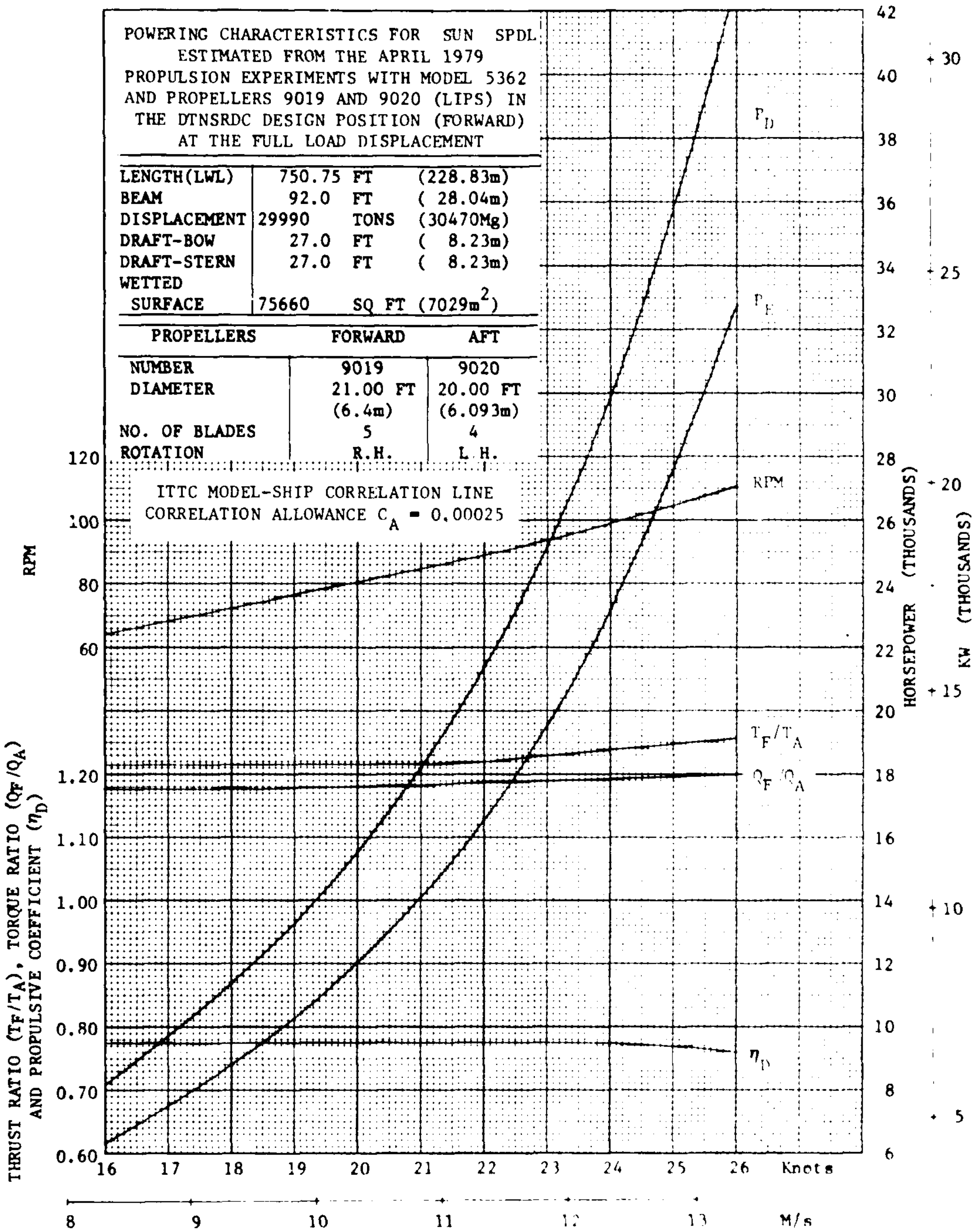


Figure 32 - Full Load Displacement Powering Characteristics for the Stretched PONCE DE LEON (SPDL) Class RO/RO Ship with the LIPS Design Propellers in the DTNSRDC Propeller Design Position (forward) From the April 1979 Propulsion Experiments (Model 5362 with Propellers LIPS 9019 and 9020)

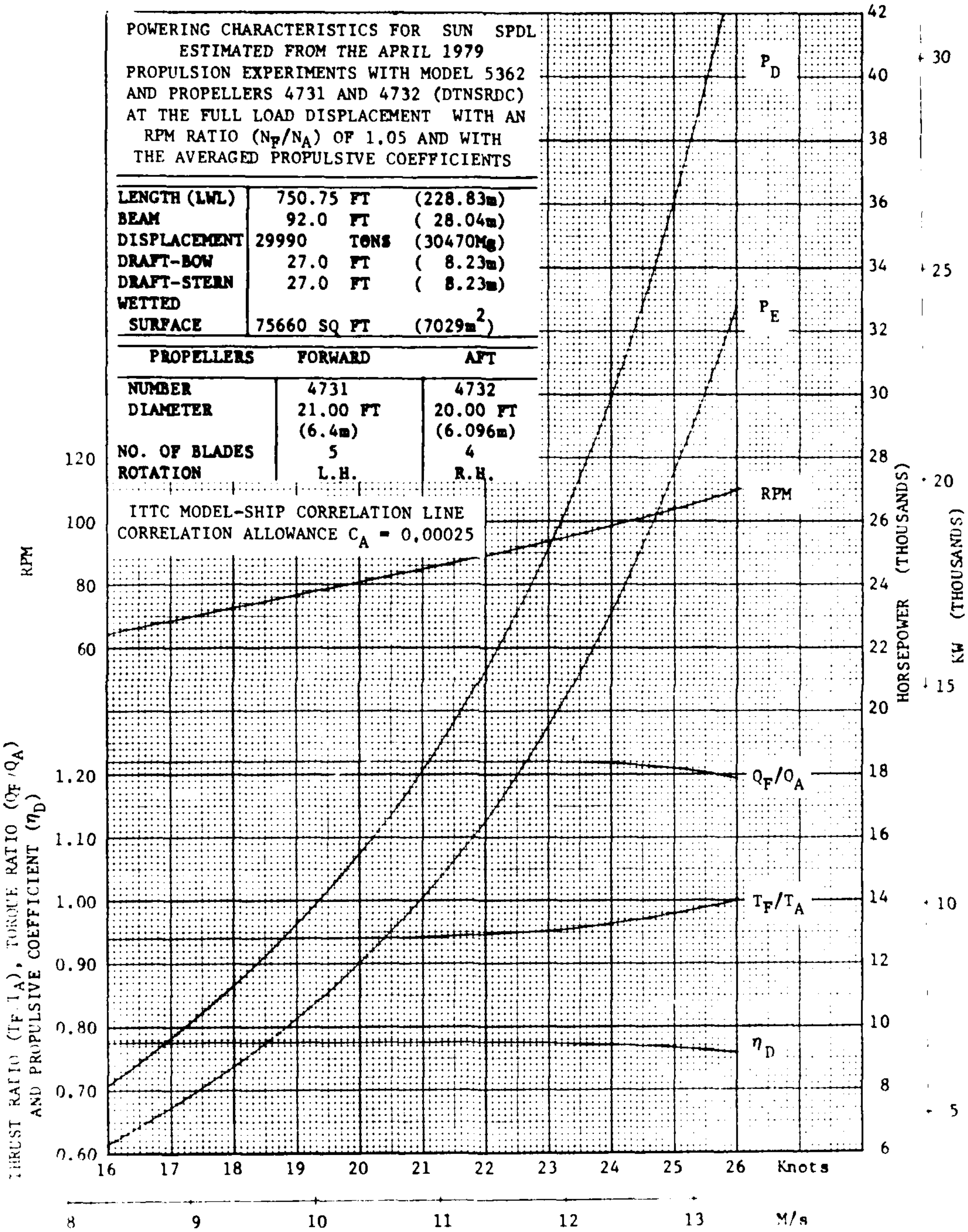


Figure 33 - Full Load Displacement Powering Characteristics for the Stretched PONCE DE LEON (SPDL) Class RO/RO Ship with the DTNSRDC Propellers at an RPM Ratio (N_F/N_A) OF 1.05 from the April 1979 Propulsion Experiments with the Original Propulsive Coefficients (Model 5362 with Propellers DTNSRDC 4731 and 4732)

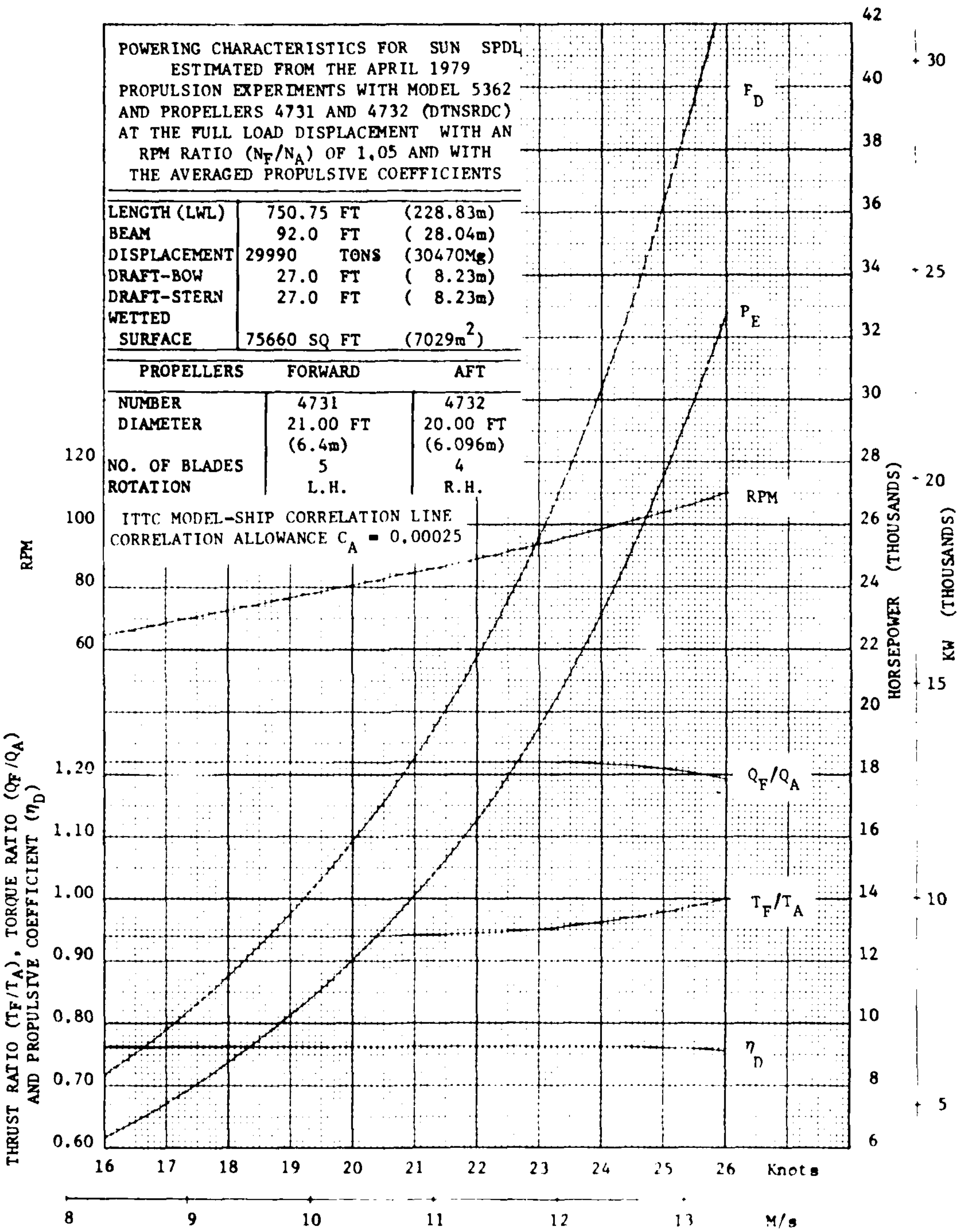


Figure 34 - Full Load Displacement Powering Characteristics for the Stretched PONCE DE LEON (SPDL) Class RO/RO Ship with the DTNSRDC Propellers at an RPM Ratio (N_F/N_A) of 1.05 From the April 1979 Propulsion Experiments with the Corrected Propulsive Coefficients (Model 5362 with Propellers DTNSRDC 4731 and 4732)

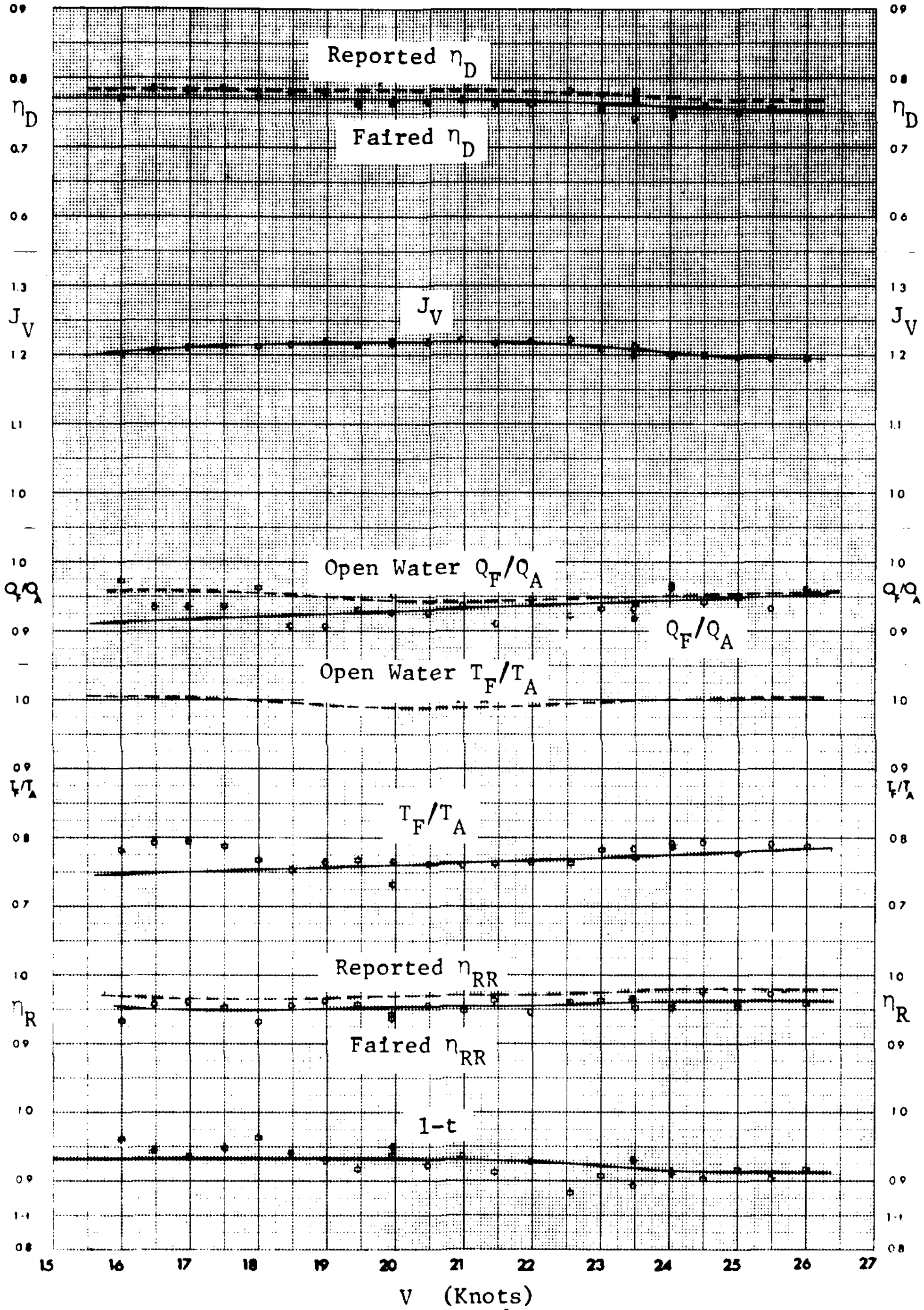


Figure 35 - Data and Faired Curves from the November 1978 Experiments with Model 5362 at the Ballast Displacement Fitted with the DTNSRDC Design Contrarotating Propellers 4731 and 4732

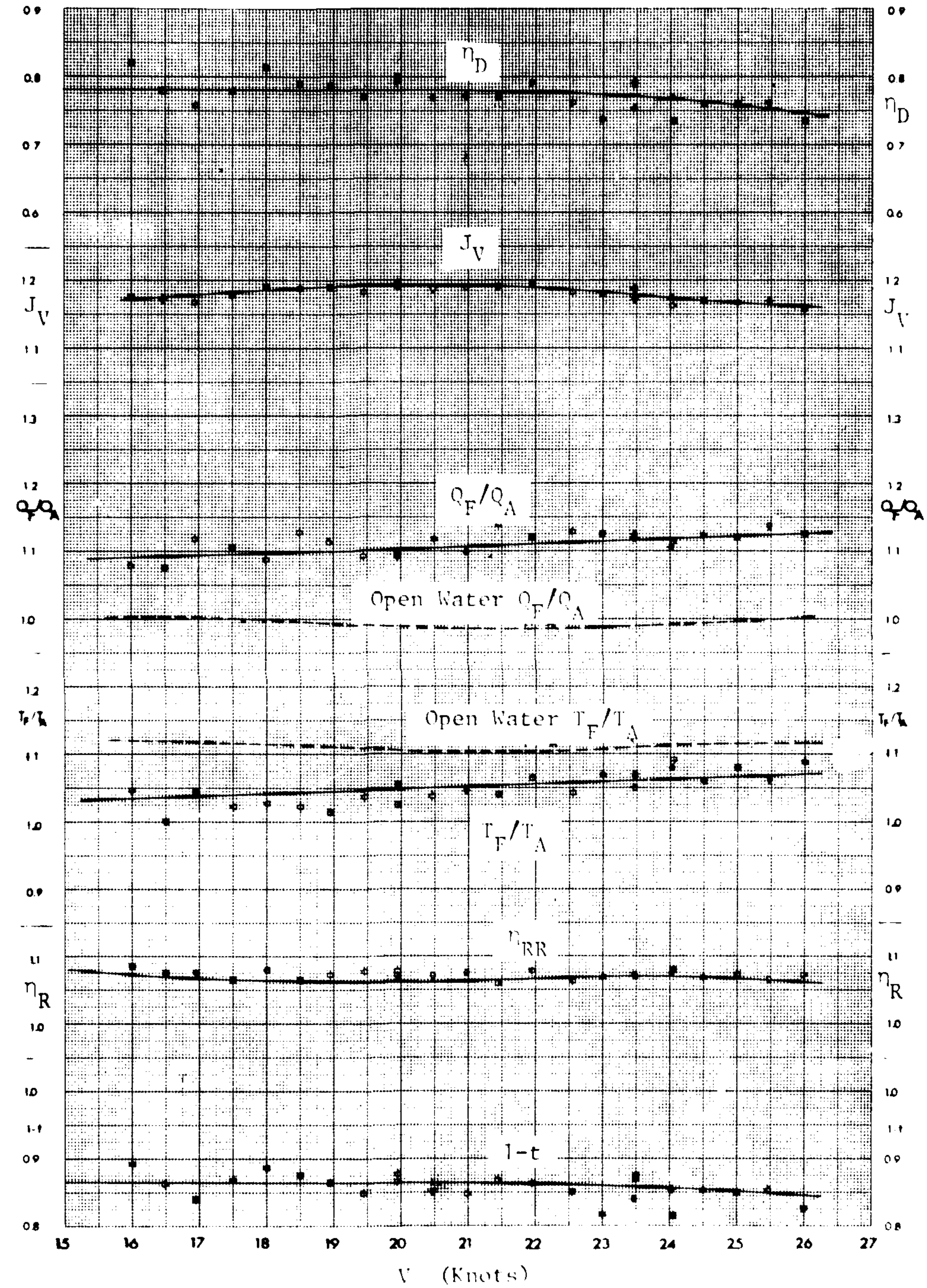


Figure 36 - Data and Faired Curves from the November 1978 Experiments with Model 5362 at the Ballast Displacement [illegible] with the LIPS Design Contrarotating Propellers [illegible]

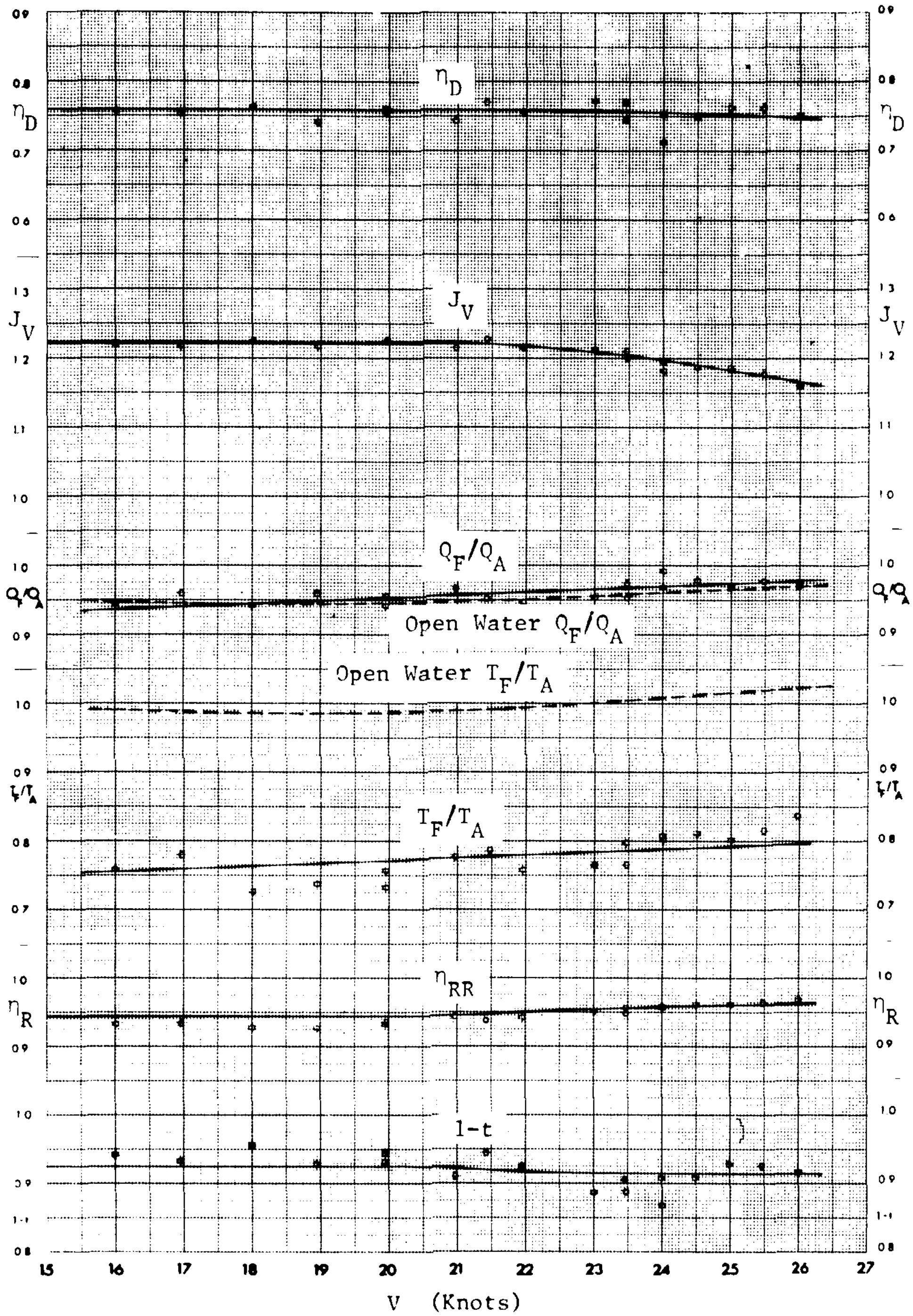


Figure 37 - Data and Faired Curves from the November 1978 Experiments with Model 5362 at the Full Load Displacement Fitted with the DTNSRDC Design Contrarotating Propellers 4731 and 4732

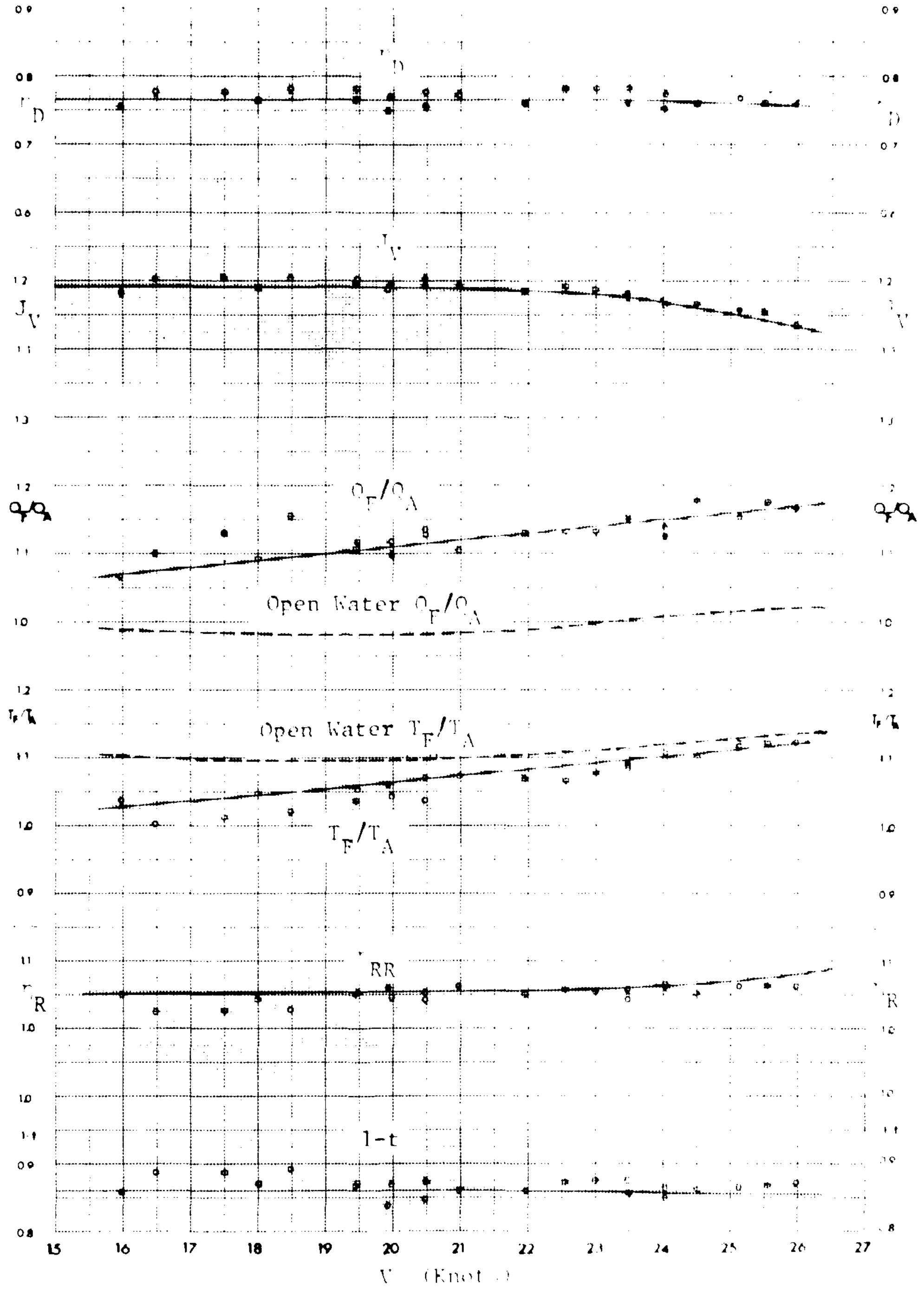


Figure 3[illegible] – Data and Faired Curves [illegible] ...riments with Model 5362 at the Full [illegible] with the LIPS Design Contract [illegible]

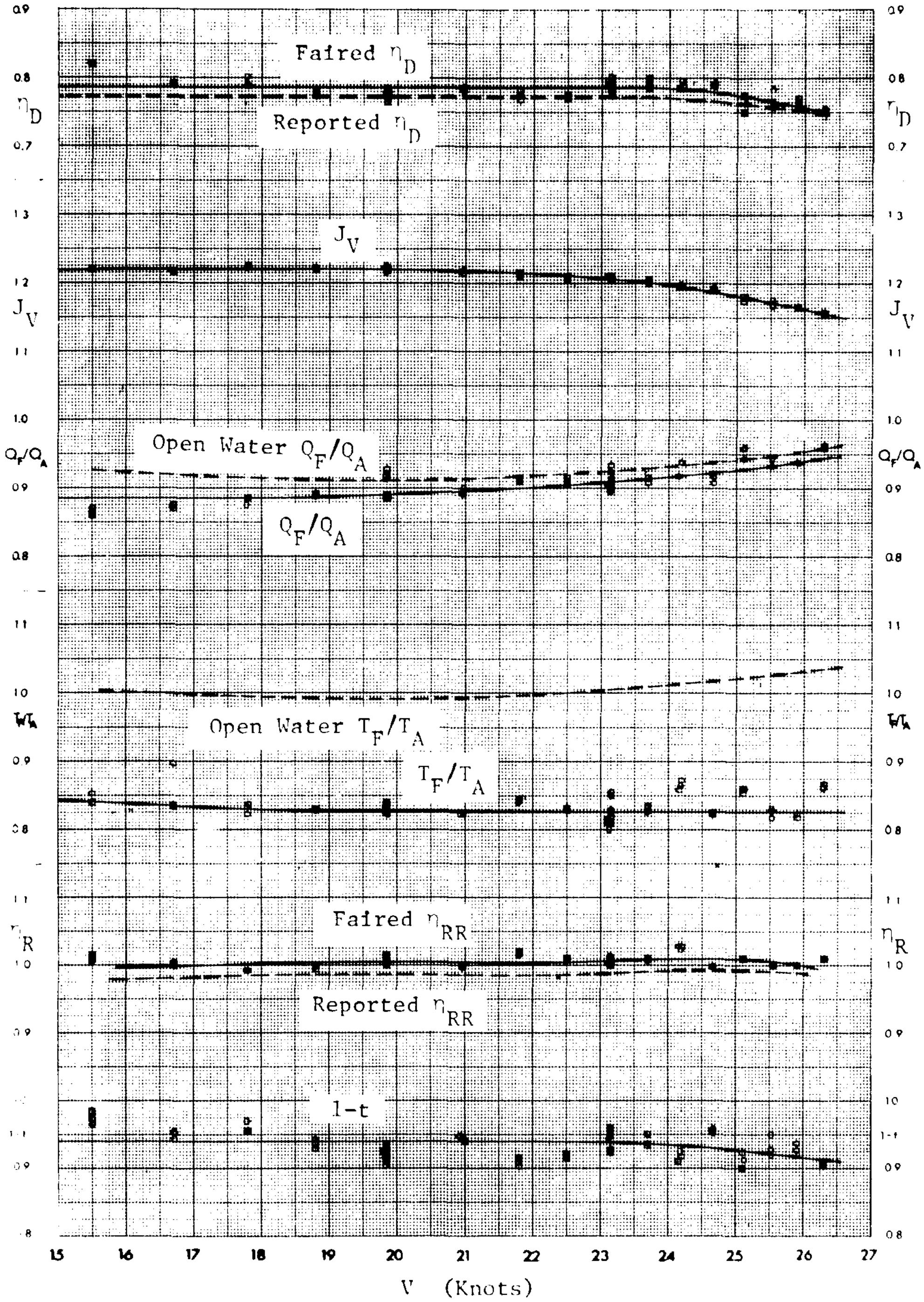


Figure 39 - Data and Faired Curves from the April 1979 Experiments with Model 5362 at the Full Load Displacement Fitted with the DTNSRDC Design Contrarotating Propellers [illegible] and 4732

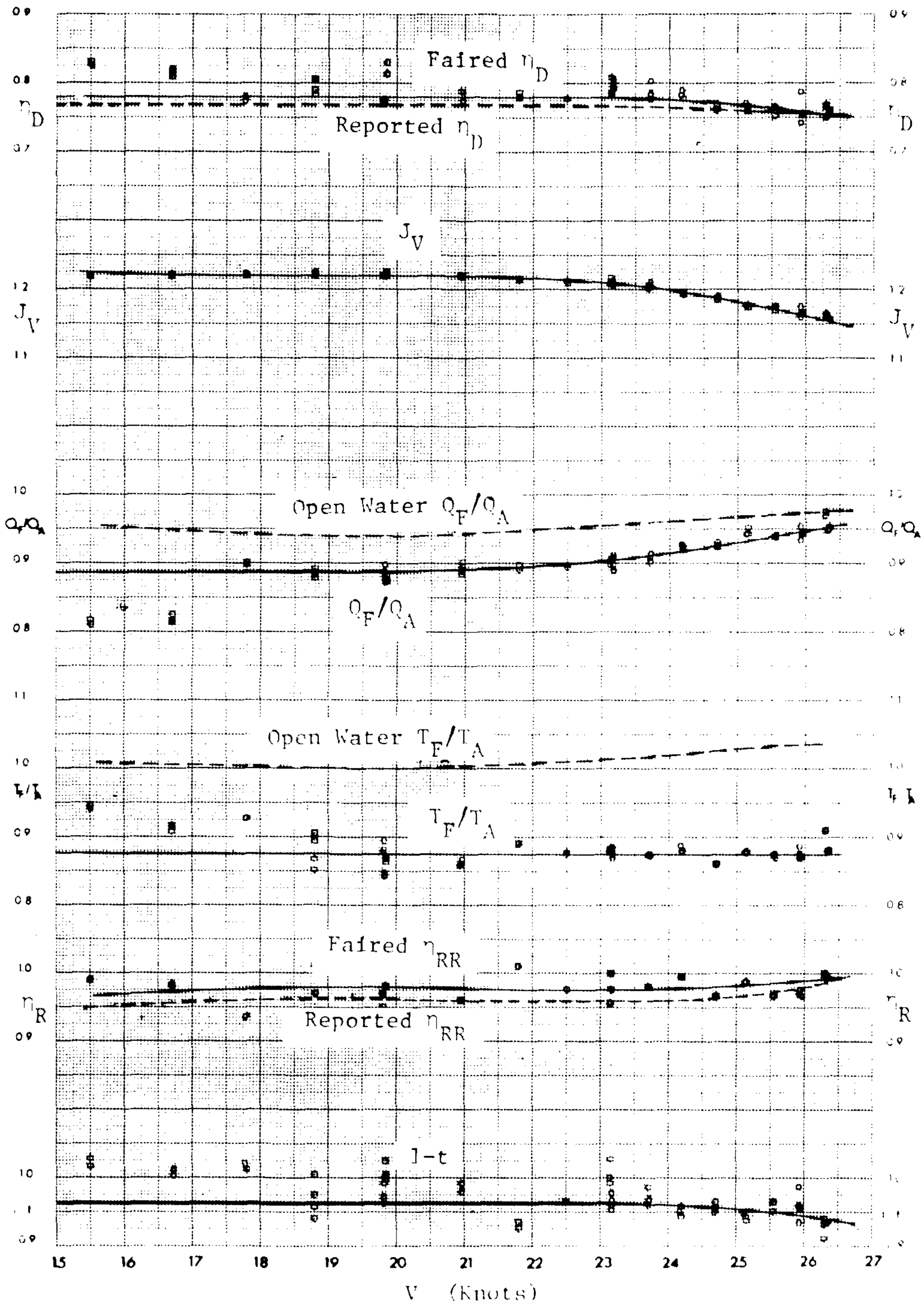


Figure 30 - Data and Faired Curves from the April 1979 Experiments with Model 5362 at the Full Load Displacement Fitted with the DTNSRDC Design Contrarotating Propellers 4731 and 4732 in the LIPS Propellers Design Position (Aft)

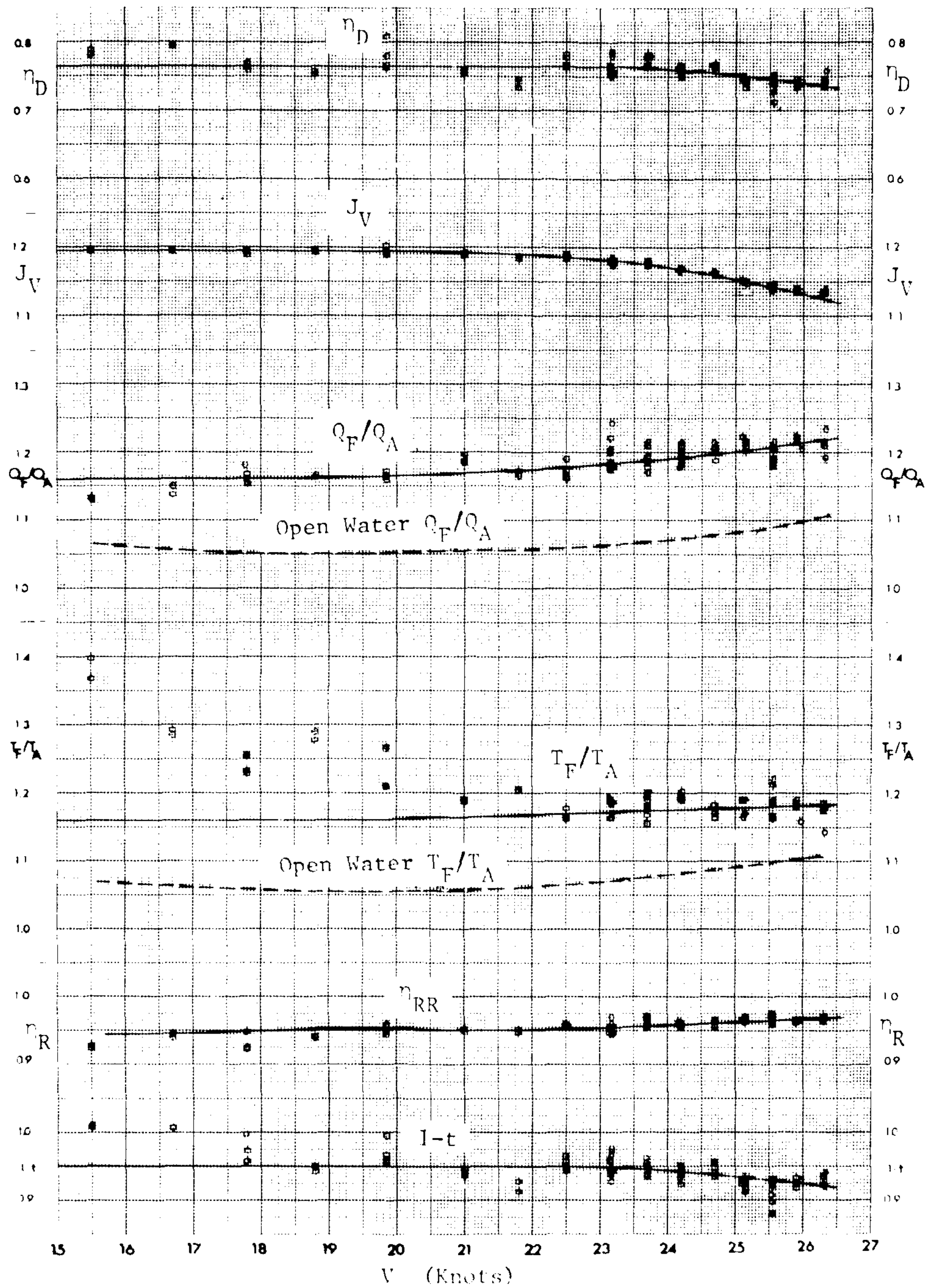


Figure 41 - Data and Faired Curves from the April 1979 Experiments with Model 5362 at the Full Load Displacement Fitted with the LIPS Design Contrarotating Propellers [illegible]

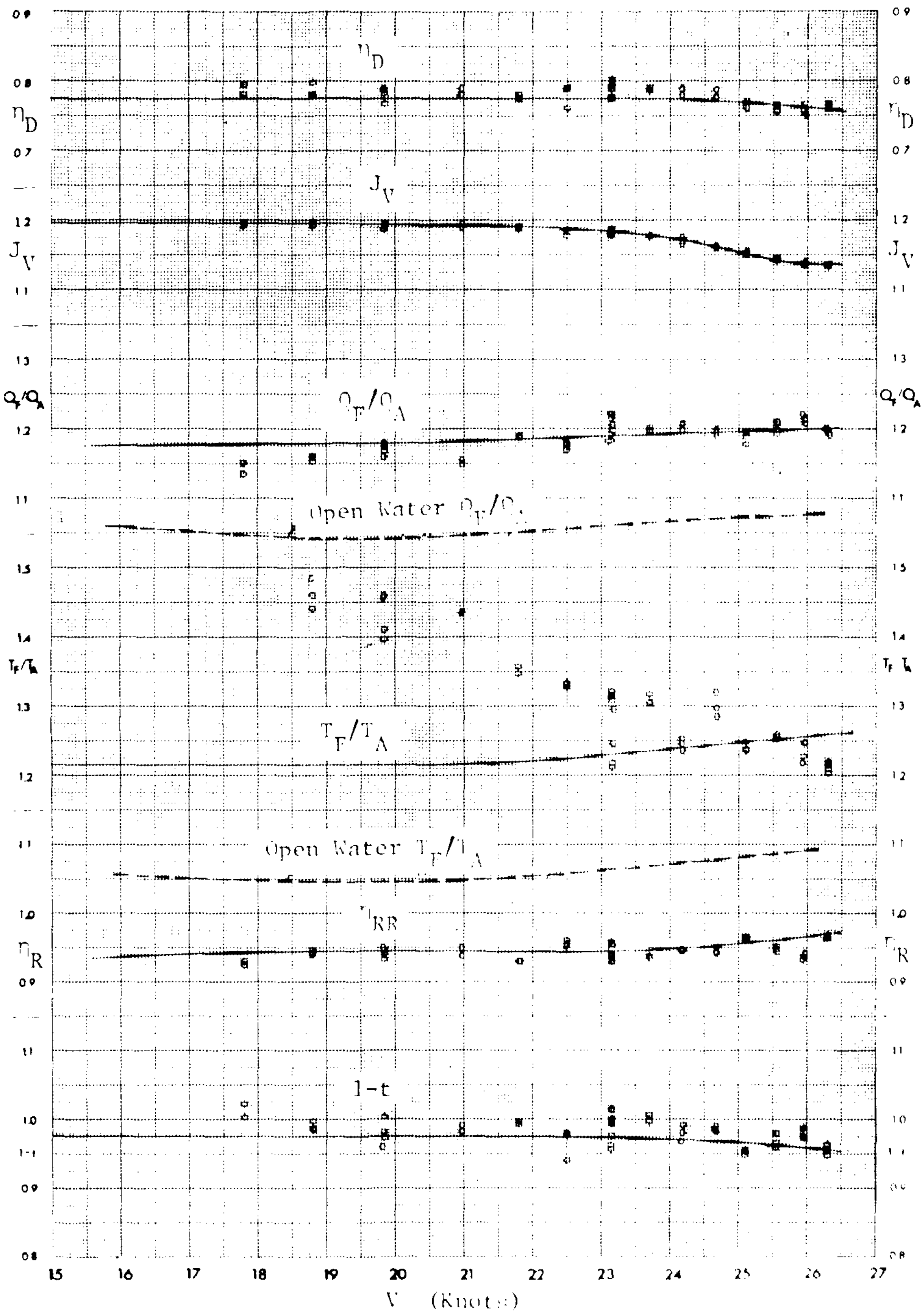


Figure 52 - Data and Faired Curves From the April [illegible] Experiments with Model 5362 at the Full Load Displacement Fitted with the JIPS Design Contrarotating Propellers [illegible] 020 in the DTNSRDC Propeller [illegible]

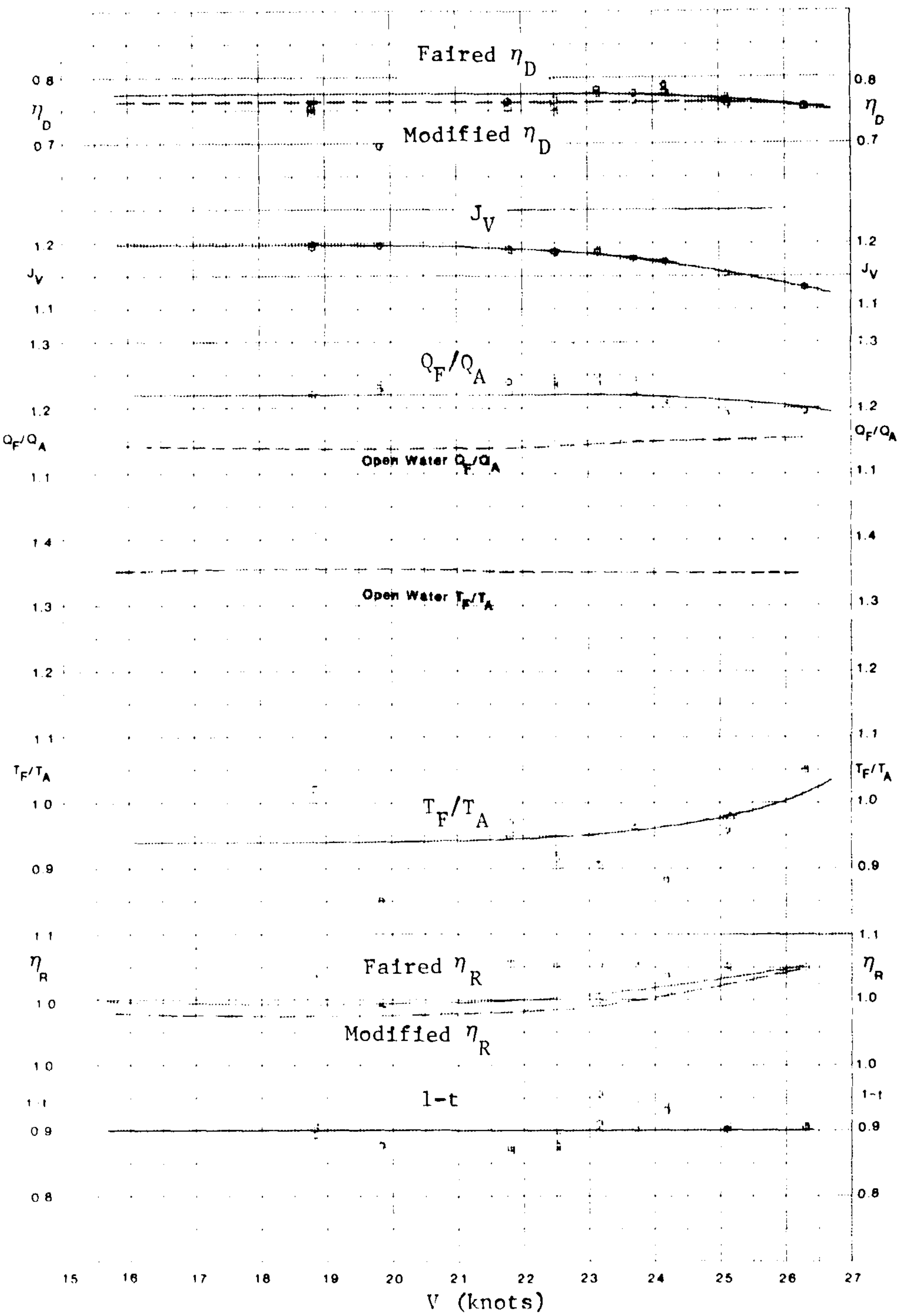


Figure 43 - Data and Faired Curves from the April 1979 Experiments with Model 5362 at the Full Load Displacement Fitted with the DTNSRDC Design Contrarotating Propellers 4731 and 4732 at an RPM Ratio (N_F/N_A) of 1.05

TABLE 1

Principal Dimensions of the Stretched PONCE DE LEON (SPDL) RO/RO Ship and Model 5362

	SHIP		MODEL	
Length - overall	790.75 ft	(241.02 m)	31.38 ft	(9.56 m)
Length - waterline	750.75 ft	(228.83 m)	29.79 ft	(9.08 m)
Length between perpendiculars	733.75 ft	(223.65 m)	29.12 ft	(8.88 m)
Beam - molded	92.0 ft	(28.04 m)	3.65 ft	(1.11 m)
Displacement				
Full Load	30060 tons	(30540 t)	4208 lbs	(1908 kg)
Ballast	22535 tons	(22900 t)	3154 lbs	(1431 kg)
Draft				
Full Load	27.0 ft	(8.23 m)	1.07 ft	(0.33 m)
Ballast				
Bow	16.0 ft	(4.88 m)	0.64 ft	(0.19 m)
Stern	27.0 ft	(8.23 m)	1.07 ft	(0.33 m)

Table 2
Measured and Design Offsets from Propeller 4731 (DTNSRDC Forward)
1 inch = 25.4 mm

Blade Number	ΔZ (Inches)	Δθ (Degrees)	Pitch (Inches)	Design Pitch (Inches)	Percentage Pitch Error
Radius 50%					
1	1.4072	38.62	13.12	13.352	-1.74
2	1.4073	38.67	13.10		-1.89
3	1.4144	38.57	13.20		-1.14
4	1.4006	38.67	13.04		-2.34
Radius 70%					
1	1.0404	28.67	13.06	13.360	-2.25
2	1.0433	28.52	13.17		-1.42
3	1.0480	28.48	13.24		-0.83
4	1.0428	28.50	13.17		-1.42
5	1.0407	28.50	13.15		-1.58
Radius 90%					
1	.5742	16.77	12.33	12.600	-2.14
2	.5784	16.83	12.37		-1.83
3	.5864	16.92	12.48		-0.93
4	.5692	16.55	12.38		-1.75
5	.5717	16.60	12.40		-1.59

MAXIMUM THICKNESS (INCHES)

Blade Number	50% R	70%	90% R
Design Value	.195	.136	.099
1	.197	.142	.104
2	.201	.143	.106
3	.199	.143	.106
4	.201	.142	.100
5	.201	.143	.105

Table 3
Measured and Design Offsets from Propeller 4732 (DTNSRDC Aft)
1 inch = 25.4 mm

Blade Number	ΔZ (Inches)	Δθ (Degrees)	Pitch (Inches)	Design Pitch (Inches)	Percentage Pitch Error
Radius 50%					
1	1.4428	37.66	13.79	13.905	-0.83
2	1.4405	37.78	13.73		-1.26
3	1.4429	37.87	13.72		-1.33
4	1.4408	37.47	13.84		-0.47
Radius 90%					
1	1.0734	28.47	13.57	13.714	-1.05
2	1.0735	28.58	13.52		-1.41
3	1.0784	28.70	13.53		-1.34
4	1.0677	28.16	13.65		-0.47
Radius 70%					
1	.5838	16.97	12.37	12.524	-1.23
2	.5832	16.98	12.36		-1.31
3	.5903	17.23	12.33		-1.55
4	.5883	16.87	12.55		+0.21

MAXIMUM THICKNESS (INCHES)

Blade Number	50% R	70% R	90% R
Design Value	.186	.130	.094
1	.197	.141	.100
2	.196	.138	.097
3	.201	.144	.102
4	.193	.138	.096

Table 4
Measured and Design Offsets from Propeller 9019 (LIPS Forward)
1 inch = 25.4 mm

Blade Number	ΔZ (Inches)	ΔΘ (Degrees)	Pitch (Inches)	Design Pitch (Inches)	Percentage Pitch Error
Radius 50%					
1	1.398	39.67	12.688	12.706	-0.1
2	1.396	39.70	12.659		-0.4
3	1.398	39.73	12.667		-0.3
4	1.400	39.68	12.717		+0.1
5	1.393	39.68	12.637		-0.5
Radius 70%					
1	1.177	32.95	12.859	12.744	+0.9
2	1.180	33.10	12.834		+0.7
3	1.178	33.07	12.825		+0.6
4	1.173	33.10	12.758		+0.1
5	1.183	33.03	12.893		+1.1
Radius 90%					
1	.817	23.72	12.295	12.220	+0.6
2	.819	23.87	12.354		+1.1
3	.823	23.85	12.423		+1.7
4	.819	23.80	12.388		+1.4
5	.816	23.70	12.395		+1.4

MAXIMUM THICKNESS (INCHES)

Blade Number	50% R	70% R	90% R
Design Value	.216	.127	.051
1	.228	.127	.036
2	.223	.133	.062
3	.227	.135	.068
4	.225	.133	.062
5	.221	.133	.061

Table 5
Measured and Design Offsets from Propeller 9020 (LIPS Aft)

1 inch = 25.4 mm

Blade Number	ΔZ (Inches)	ΔΘ (Degrees)	Pitch (Inches)	Design Pitch (Inches)	Percentage Pitch Error
Radius 50%					
1	1.509	42.20	12.873	12.759	+0.9
2	1.509	42.37	12.822		+0.5
3	1.498	42.32	12.444		-2.5
4	1.511	42.18	12.895		-1.1
Radius 70%					
1	1.207	33.10	13.127	12.934	+1.5
2	1.198	33.18	12.997		+0.5
3	1.201	33.20	12.997		+0.5
4	1.205	33.08	13.112		+1.4
Radius 90%					
1	.690	20.20	12.297	12.014	+2.4
2	.695	20.42	12.255		+2.0
3	.700	20.65	12.203		+1.6
4	.706	20.53	12.378		+3.0

MAXIMUM THICKNESS (INCHES)

Blade Number	50% R	70% R	90% R
Design Value	.193	.110	.051
1	.197	.113	.051
2	.197	.113	.051
3	.198	.116	.053
4	.197	.113	.051

Table 6

BALLAST DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE DTNSRDC DESIGN PROPELLERS FROM THE NOVEMBER 1978 PROPULSION EXPERIMENTS WITH THE ORIGINAL PROPULSIVE COEFFICIENTS (MODEL 5362 WITH PROPELLERS DTNSRDC 4731 AND 4732)

SHIP SPEED		EFFECTIVE POWER(PE)		DELIVERED POWER(PD)		PROPELLER REVOLUTIONS PER MINUTE	T_F/T_A	Q_F/Q_A
(KNOTS)	(M/SEC)	(HORSE-POWER)	(KILO-WATTS)	(HORSE-POWER)	(KILO-WATTS)			
16.0	8.23	6800.	5070.	8830.	6580.	64.1	.747	.912
17.0	8.75	8020.	5980.	10420.	7770.	67.8	.750	.916
18.0	9.26	9300.	6930.	12080.	9010.	71.5	.753	.920
19.0	9.77	10670.	7960.	13860.	10330.	75.3	.757	.924
20.0	10.29	12190.	9090.	15840.	11810.	79.2	.761	.928
21.0	10.80	14000.	10440.	18200.	13570.	83.1	.764	.932
22.0	11.32	16250.	12120.	21180.	15800.	87.2	.767	.936
23.0	11.83	18970.	14140.	24820.	18510.	91.5	.770	.940
23.1	11.88	19260.	14370.	25250.	18830.	92.0	.770	.940
24.0	12.35	22080.	16470.	29130.	21720.	96.3	.775	.944
25.0	12.86	25360.	18910.	33640.	25080.	100.8	.779	.947
26.0	13.38	28750.	21440.	38190.	28480.	105.0	.783	.952

SHIP SPEED	EFFICIENCIES(ETA)				THRUST DEDUCTION AND WAKE FACTORS			ADVANCE COEF.
(KNOTS)	ETAD	ETAO	ETAH	ETAR	1-THDF	1-WFTT	1-WFTQ	ADVC
16.0	.770	.750	1.075	.955	.930	.865	.845	1.045
17.0	.770	.755	1.080	.950	.930	.865	.840	1.045
18.0	.770	.755	1.075	.950	.930	.870	.845	1.055
19.0	.770	.760	1.065	.950	.930	.875	.850	1.060
20.0	.770	.760	1.060	.955	.930	.880	.855	1.070
21.0	.770	.760	1.060	.955	.930	.880	.860	1.070
22.0	.765	.760	1.055	.955	.925	.875	.855	1.070
23.0	.765	.760	1.055	.960	.920	.875	.855	1.060
23.1	.765	.760	1.050	.960	.920	.875	.855	1.060
24.0	.760	.755	1.045	.960	.915	.875	.860	1.055
25.0	.755	.755	1.040	.960	.915	.875	.860	1.050
26.0	.755	.755	1.040	.960	.915	.875	.860	1.050

Table 7

BALLAST DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE DTNSRDC DESIGN PROPELLERS FROM THE NOVEMBER 1978 PROPULSION EXPERIMENTS WITH THE CORRECTED PROPULSIVE COEFFICIENTS (MODEL 5362 WITH PROPELLERS DTNSRDC 4731 AND 4732)

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER(PE) (HORSE-POWER)	EFFECTIVE POWER(PE) (KILO-WATTS)	DELIVERED POWER(PD) (HORSE-POWER)	DELIVERED POWER(PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE	T_F/T_A	Q_F/Q_A
16.0	8.23	6800.	5070.	8670.	6470.	64.1	.747	.912
17.0	8.75	8020.	5980.	10230.	7630.	67.8	.750	.916
18.0	9.26	9300.	6930.	11860.	8840.	71.5	.753	.920
19.0	9.77	10670.	7960.	13610.	10150.	75.3	.757	.924
20.0	10.29	12190.	9090.	15550.	11600.	79.2	.761	.928
21.0	10.80	14000.	10440.	17880.	13330.	83.1	.764	.932
22.0	11.32	16250.	12120.	20800.	15510.	87.2	.767	.936
23.0	11.83	18970.	14140.	24380.	18180.	91.5	.770	.940
23.1	11.88	19260.	14370.	24790.	18490.	92.0	.770	.940
24.0	12.35	22080.	16470.	28600.	21330.	96.3	.775	.944
25.0	12.86	25360.	18910.	33020.	24630.	100.8	.779	.947
26.0	13.38	28750.	21440.	37490.	27960.	105.0	.783	.952

SHIP SPEED (KNOTS)	EFFICIENCIES(ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
16.0	.785	.750	1.075	.970	.930	.865	.855	1.045
17.0	.785	.755	1.080	.965	.930	.865	.850	1.045
18.0	.785	.755	1.075	.965	.930	.870	.855	1.055
19.0	.785	.760	1.065	.970	.930	.875	.860	1.060
20.0	.785	.760	1.060	.970	.930	.880	.865	1.070
21.0	.785	.760	1.060	.970	.930	.880	.870	1.070
22.0	.780	.760	1.055	.970	.925	.875	.865	1.070
23.0	.780	.760	1.055	.975	.920	.875	.865	1.060
23.1	.775	.760	1.050	.975	.920	.875	.865	1.060
24.0	.770	.755	1.045	.980	.915	.875	.865	1.055
25.0	.770	.755	1.040	.980	.915	.875	.870	1.050
26.0	.765	.755	1.040	.980	.915	.875	.865	1.050

Table 8

BALLAST DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE LIPS DESIGN PROPELLERS FROM THE NOVEMBER 1978 PROPULSION EXPERIMENTS (MODEL 5362 WITH PROPELLERS LIPS 9019 AND 9020)

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER(PE) (HORSE-POWER)	EFFECTIVE POWER(PE) (KILO-WATTS)	DELIVERED POWER(PD) (HORSE-POWER)	DELIVERED POWER(PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE	T_F/T_A	Q_F/Q_A
16.0	8.23	6800.	5070.	8720.	6500.	65.8	1.035	1.090
17.0	8.75	8020.	5980.	10280.	7670.	69.5	1.038	1.093
18.0	9.26	9300.	6930.	11920.	8890.	73.3	1.042	1.096
19.0	9.77	10670.	7960.	13680.	10200.	77.0	1.045	1.099
20.0	10.29	12190.	9090.	15630.	11660.	80.9	1.048	1.102
21.0	10.80	14000.	10440.	17970.	13400.	84.9	1.052	1.106
22.0	11.32	16250.	12120.	20880.	15570.	89.2	1.055	1.110
23.0	11.83	18970.	14140.	24470.	18250.	93.8	1.059	1.114
23.1	11.88	19260.	14370.	24890.	18560.	94.3	1.060	1.115
24.0	12.35	22080.	16470.	28750.	21440.	98.6	1.063	1.117
25.0	12.86	25360.	18910.	33410.	24920.	103.4	1.066	1.121
26.0	13.38	28750.	21440.	38490.	28700.	107.9	1.070	1.125

SHIP SPEED	EFFICIENCIES(ETA)				THRUST DEDUCTION AND WAKE FACTORS			ADVANCE COEF.
(KNOTS)	ETAD	ETAO	ETAH	ETAR	1-THDF	1-WFTT	1-WFTQ	ADVC
16.0	.780	.710	1.020	1.075	.865	.845	.875	.995
17.0	.780	.715	1.025	1.070	.865	.845	.870	.995
18.0	.780	.715	1.025	1.065	.865	.845	.870	1.000
19.0	.780	.720	1.020	1.060	.865	.845	.870	1.005
20.0	.780	.720	1.020	1.060	.865	.850	.875	1.015
21.0	.780	.725	1.015	1.065	.865	.850	.875	1.015
22.0	.780	.720	1.010	1.065	.860	.855	.880	1.015
23.0	.775	.720	1.005	1.070	.860	.855	.880	1.010
23.1	.775	.720	1.005	1.070	.860	.855	.880	1.010
24.0	.770	.715	1.000	1.070	.855	.855	.880	1.005
25.0	.760	.715	.995	1.070	.850	.860	.885	1.000
26.0	.745	.715	.985	1.060	.845	.860	.885	.995

Table 9

FULL LOAD DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE DTNSRDC DESIGN PROPELLERS FROM THE NOVEMBER 1978 PROPULSION EXPERIMENTS (MODEL 5362 WITH PROPELLERS DTNSRDC 4731 AND 4732)

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER(PE) (HORSE-POWER)	EFFECTIVE POWER(PE) (KILO-WATTS)	DELIVERED POWER(PD) (HORSE-POWER)	DELIVERED POWER(PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE	T_F/T_A	Q_F/Q_A
16.0	8.23	6330.	4720.	8350.	6230.	63.1	.755	.935
17.0	8.75	7500.	5590.	9900.	7380.	67.1	.759	.939
18.0	9.26	8790.	6560.	11600.	8650.	71.0	.767	.947
19.0	9.77	10260.	7650.	13540.	10100.	75.0	.755	.943
20.0	10.29	12040.	8980.	15880.	11840.	78.9	.771	.951
21.0	10.80	14090.	10510.	18590.	13860.	82.9	.775	.956
22.0	11.32	16530.	12320.	21800.	16260.	87.0	.780	.960
23.0	11.83	19480.	14520.	25690.	19160.	91.6	.784	.964
23.1	11.88	19810.	14770.	26130.	19480.	92.1	.785	.965
24.0	12.35	23140.	17250.	30610.	22820.	96.7	.789	.969
25.0	12.86	27610.	20590.	36660.	27340.	102.0	.793	.973
26.0	13.38	32760.	24430.	43800.	32660.	107.6	.798	.978

SHIP SPEED (KNOTS)	EFFICIENCIES(ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
16.0	.760	.755	1.070	.935	.925	.865	.835	1.060
17.0	.760	.760	1.065	.940	.925	.870	.845	1.065
18.0	.760	.760	1.060	.940	.925	.875	.850	1.070
19.0	.760	.760	1.055	.945	.925	.875	.850	1.070
20.0	.760	.760	1.055	.940	.925	.875	.850	1.070
21.0	.760	.760	1.060	.940	.925	.870	.845	1.065
22.0	.760	.755	1.060	.945	.915	.865	.840	1.055
23.0	.760	.755	1.060	.950	.915	.865	.840	1.045
23.1	.760	.750	1.060	.950	.915	.865	.840	1.045
24.0	.755	.750	1.055	.955	.915	.865	.845	1.035
25.0	.755	.745	1.055	.960	.915	.865	.845	1.025
26.0	.750	.740	1.055	.960	.915	.870	.850	1.010

Table 10

FULL LOAD DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE DTNSRDC DESIGN PROPELLERS FROM THE APRIL 1979 PROPULSION EXPERIMENTS WITH THE ORIGINAL PROPULSIVE COEFFICIENTS (MODEL 5362 WITH PROPELLERS DTNSRDC 4731 AND 4732)

SHIP SPEED		EFFECTIVE POWER(PE)		DELIVERED POWER(PD)		PROPELLER	T_F/T_A	Q_F/Q_A
		(HORSE-	(KILO-	(HORSE-	(KILO-	REVOLUTIONS		
(KNOTS)	(M/SEC)	POWER)	WATTS)	POWER)	WATTS)	PER MINUTE		
16.0	8.23	6330.	4720.	8050.	6000.	63.2	.838	.868
17.0	8.75	7500.	5590.	9540.	7120.	67.1	.832	.874
18.0	9.26	8790.	6560.	11190.	8340.	71.1	.829	.879
19.0	9.77	10260.	7650.	13060.	9740.	75.0	.827	.885
20.0	10.29	12040.	8980.	15310.	11420.	79.1	.826	.890
21.0	10.80	14090.	10510.	17930.	13370.	83.1	.826	.896
22.0	11.32	16530.	12320.	21030.	15680.	87.3	.826	.902
23.0	11.83	19480.	14520.	24780.	18480.	91.9	.826	.908
23.1	11.88	19810.	14770.	25200.	18790.	92.4	.826	.909
24.0	12.35	23140.	17250.	29480.	21980.	96.7	.826	.917
25.0	12.86	27610.	20590.	35620.	26560.	102.0	.826	.927
26.0	13.38	32760.	24430.	43280.	32270.	107.4	.826	.940

SHIP SPEED	EFFICIENCIES(ETA)				THRUST DEDUCTION AND WAKE FACTORS			ADVANCE COEF.
(KNOTS)	ETAD	ETAO	ETAH	ETAR	1-THDF	1-WFTT	1-WFTQ	ADVC
16.0	.785	.730	1.080	.995	.940	.870	.865	1.060
17.0	.785	.730	1.075	1.000	.940	.875	.875	1.065
18.0	.785	.730	1.070	1.000	.940	.875	.880	1.070
19.0	.785	.730	1.070	1.005	.940	.880	.880	1.075
20.0	.785	.730	1.070	1.005	.940	.880	.880	1.070
21.0	.785	.730	1.070	1.005	.940	.880	.880	1.070
22.0	.785	.730	1.075	1.005	.940	.875	.875	1.065
23.0	.785	.730	1.075	1.005	.940	.875	.875	1.055
23.1	.785	.730	1.075	1.005	.940	.875	.875	1.055
24.0	.785	.725	1.075	1.010	.935	.870	.875	1.040
25.0	.775	.720	1.070	1.010	.925	.865	.870	1.025
26.0	.755	.715	1.065	.995	.920	.865	.860	1.005

Table 11

FULL LOAD DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE DTNSRDC DESIGN PROPELLERS FROM THE APRIL 1979 PROPULSION EXPERIMENTS WITH THE AVERAGED PROPULSIVE COEFFICIENTS (MODEL 5362 WITH PROPELLERS DTNSRDC 4731 AND 4732)

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER(PE) (HORSE-POWER)	EFFECTIVE POWER(PE) (KILO-WATTS)	DELIVERED POWER(PD) (HORSE-POWER)	DELIVERED POWER(PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE	T_F/T_A	Q_F/Q_A
16.0	8.23	6330.	4720.	8200.	6110.	63.2	.838	.868
17.0	8.75	7500.	5590.	9720.	7250.	67.1	.832	.874
18.0	9.26	8790.	6560.	11390.	8490.	71.1	.829	.879
19.0	9.77	10260.	7650.	13300.	9920.	75.0	.827	.885
20.0	10.29	12040.	8980.	15590.	11630.	79.1	.826	.890
21.0	10.80	14090.	10510.	18250.	13610.	83.1	.826	.896
22.0	11.32	16530.	12320.	21410.	15960.	87.3	.826	.902
23.0	11.83	19480.	14520.	25230.	18810.	91.9	.826	.908
23.1	11.88	19810.	14770.	25660.	19130.	92.4	.826	.909
24.0	12.35	23140.	17250.	30010.	22380.	96.7	.826	.917
25.0	12.86	27610.	20590.	36140.	26950.	102.0	.826	.927
26.0	13.38	32760.	24430.	43630.	32530.	107.4	.826	.940

SHIP SPEED (KNOTS)	EFFICIENCIES(ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
16.0	.770	.730	1.080	.980	.940	.870	.860	1.060
17.0	.770	.730	1.075	.980	.940	.875	.865	1.065
18.0	.770	.730	1.070	.985	.940	.875	.870	1.070
19.0	.770	.730	1.070	.985	.940	.880	.875	1.075
20.0	.770	.730	1.070	.985	.940	.880	.875	1.070
21.0	.770	.730	1.070	.985	.940	.880	.870	1.070
22.0	.770	.730	1.075	.985	.940	.875	.870	1.065
23.0	.770	.730	1.075	.990	.940	.875	.870	1.055
23.1	.770	.730	1.075	.990	.940	.875	.870	1.055
24.0	.770	.725	1.075	.990	.935	.870	.865	1.040
25.0	.765	.720	1.070	.995	.925	.865	.865	1.025
26.0	.750	.715	1.065	.990	.920	.865	.855	1.005

Table 12

FULL LOAD DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE DTNSRDC DESIGN PROPELLERS IN THE LIPS PROPELLER DESIGN POSITION (AFT) FROM THE APRIL 1979 PROPULSION EXPERIMENTS WITH THE ORIGINAL PROPULSIVE COEFFICIENTS (MODEL 5362 WITH PROPELLERS DTNSRDC 4731 AND 4732)

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER(PE) (HORSE-POWER)	EFFECTIVE POWER(PE) (KILO-WATTS)	DELIVERED POWER(PD) (HORSE-POWER)	DELIVERED POWER(PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE	T_F/T_A	Q_F/Q_A
16.0	8.23	6330.	4720.	8110.	6050.	63.1	.875	.887
17.0	8.75	7500.	5590.	9620.	7170.	67.1	.875	.887
18.0	9.26	8790.	6560.	11270.	8410.	71.1	.875	.887
19.0	9.77	10260.	7650.	13160.	9810.	75.1	.875	.887
20.0	10.29	12040.	8980.	15430.	11510.	79.1	.875	.889
21.0	10.80	14090.	10510.	18070.	13470.	83.1	.875	.891
22.0	11.32	16530.	12320.	21190.	15800.	87.2	.875	.895
23.0	11.83	19480.	14520.	24970.	18620.	91.7	.875	.902
23.1	11.88	19810.	14770.	25390.	18940.	92.1	.875	.903
24.0	12.35	23140.	17250.	29740.	22180.	96.5	.875	.914
25.0	12.86	27610.	20590.	35850.	26740.	102.1	.875	.929
26.0	13.38	32760.	24430.	43170.	32190.	107.9	.875	.947

SHIP SPEED (KNOTS)	EFFICIENCIES(ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
16.0	.780	.730	1.100	.970	.965	.875	.860	1.070
17.0	.780	.735	1.095	.975	.965	.880	.870	1.075
18.0	.780	.735	1.090	.975	.965	.885	.875	1.080
19.0	.780	.735	1.085	.980	.965	.890	.880	1.085
20.0	.780	.735	1.085	.980	.965	.885	.875	1.080
21.0	.780	.735	1.090	.975	.965	.885	.875	1.080
22.0	.780	.730	1.095	.975	.965	.880	.870	1.075
23.0	.780	.730	1.095	.975	.965	.880	.870	1.065
23.1	.780	.730	1.095	.975	.965	.880	.870	1.065
24.0	.780	.725	1.095	.980	.960	.875	.865	1.050
25.0	.770	.725	1.085	.980	.955	.880	.870	1.040
26.0	.760	.720	1.070	.985	.945	.880	.875	1.025

Table 13

FULL LOAD DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE DTNSRDC DESIGN PROPELLERS IN THE LIPS PROPELLER DESIGN POSITION (AFT) FROM THE APRIL 1979 PROPULSION EXPERIMENTS WITH THE CORRECTED PROPULSIVE COEFFICIENTS (MODEL 5362 WITH PROPELLERS DTNSRDC 4731 AND 4732)

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER(PE) (HORSE-POWER)	EFFECTIVE POWER(PE) (KILO-WATTS)	DELIVERED POWER(PD) (HORSE-POWER)	DELIVERED POWER(PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE	T_F/T_A	Q_F/Q_A
16.0	8.23	6330.	4720.	8250.	6150.	63.1	.875	.887
17.0	8.75	7500.	5590.	9780.	7290.	67.1	.875	.887
18.0	9.26	8790.	6560.	11470.	8550.	71.1	.875	.887
19.0	9.77	10260.	7650.	13380.	9980.	75.1	.875	.887
20.0	10.29	12040.	8980.	15690.	11700.	79.1	.875	.889
21.0	10.80	14090.	10510.	18370.	13700.	83.1	.875	.891
22.0	11.32	16530.	12320.	21550.	16070.	87.2	.875	.895
23.0	11.83	19480.	14520.	25390.	18930.	91.7	.875	.902
23.1	11.88	19810.	14770.	25820.	19260.	92.1	.875	.903
24.0	12.35	23140.	17250.	30210.	22530.	96.5	.875	.914
25.0	12.86	27610.	20590.	36370.	27120.	102.1	.875	.929
26.0	13.38	32760.	24430.	43400.	32360.	107.9	.875	.947

SHIP SPEED (KNOTS)	EFFICIENCIES(ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
16.0	.765	.730	1.100	.955	.965	.875	.855	1.070
17.0	.765	.735	1.095	.955	.965	.880	.860	1.075
18.0	.765	.735	1.090	.960	.965	.885	.870	1.080
19.0	.765	.735	1.085	.965	.965	.890	.870	1.085
20.0	.765	.735	1.085	.960	.965	.885	.870	1.080
21.0	.765	.735	1.090	.960	.965	.885	.865	1.080
22.0	.765	.730	1.095	.960	.965	.880	.865	1.075
23.0	.765	.730	1.095	.960	.965	.880	.860	1.055
23.1	.765	.730	1.095	.960	.965	.880	.860	1.065
24.0	.765	.725	1.095	.965	.960	.875	.860	1.050
25.0	.760	.725	1.085	.965	.955	.880	.860	1.040
26.0	.755	.720	1.070	.980	.945	.880	.870	1.025

Table 14

FULL LOAD DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE DTNSRDC DESIGN PROPELLERS FROM THE APRIL 1979 PROPULSION EXPERIMENTS WITH THE ORIGINAL PROPULSIVE COEFFICIENTS AND AT AN RPM RATIO (N_F/N_A) OF 1.05 (MODEL 5362 WITH PROPELLERS DTNSRDC 4731 AND 4732)

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER(PE) (HORSE-POWER)	EFFECTIVE POWER(PE) (KILO-WATTS)	DELIVERED POWER(PD) (HORSE-POWER)	DELIVERED POWER(PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE	T_F/T_A	Q_F/Q_A
16.0	8.23	6330.	4720.	8170.	6090.	64.5	.942	1.229
17.0	8.75	7500.	5590.	9680.	7220.	68.5	.942	1.229
18.0	9.26	8790.	6560.	11350.	8460.	72.5	.942	1.229
19.0	9.77	10260.	7650.	13250.	9880.	76.5	.942	1.229
20.0	10.29	12040.	8980.	15530.	11580.	80.6	.942	1.229
21.0	10.80	14090.	10510.	18180.	13560.	84.8	.943	1.229
22.0	11.32	16530.	12320.	21330.	15900.	89.2	.945	1.228
23.0	11.83	19480.	14520.	25130.	18740.	93.6	.952	1.226
23.1	11.88	19810.	14770.	25560.	19060.	94.1	.953	1.225
24.0	12.35	23140.	17250.	29930.	22320.	98.6	.962	1.219
25.0	12.86	27610.	20590.	35990.	26840.	104.2	.978	1.209
26.0	13.38	32760.	24430.	43170.	32190.	110.1	1.003	1.196

SHIP SPEED (KNOTS)	EFFICIENCIES(ETA) ETA	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
16.0	.775	.720	1.085	.995	.950	.875	.885	1.045
17.0	.775	.720	1.080	.995	.950	.880	.885	1.050
18.0	.775	.725	1.075	.990	.950	.885	.890	1.055
19.0	.775	.730	1.075	.990	.950	.885	.895	1.060
20.0	.775	.730	1.075	.990	.950	.885	.895	1.060
21.0	.775	.725	1.075	.995	.950	.885	.890	1.055
22.0	.775	.720	1.075	1.000	.950	.880	.895	1.050
23.0	.775	.715	1.080	1.005	.950	.880	.890	1.040
23.1	.775	.710	1.080	1.005	.950	.880	.890	1.040
24.0	.775	.705	1.080	1.020	.945	.875	.890	1.025
25.0	.765	.695	1.070	1.030	.940	.875	.900	1.015
26.0	.760	.685	1.060	1.045	.930	.875	.905	1.000

Table 15

FULL LOAD DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE DTNSRDC DESIGN PROPELLERS FROM THE APRIL 1979 PROPULSION EXPERIMENTS WITH THE CORRECTED PROPULSIVE COEFFICIENTS AND AT AN RPM RATIO (N_F/N_A) OF 1.05 (MODEL 5362 WITH PROPELLERS DTNSRDC 4731 AND 4732)

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER(PE) (HORSE-POWER)	EFFECTIVE POWER(PE) (KILO-WATTS)	DELIVERED POWER(PD) (HORSE-POWER)	DELIVERED POWER(PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE	T_F/T_A	Q_F/Q_A
16.0	8.23	6330.	4720.	8300.	6190.	64.5	.942	1.229
17.0	8.75	7530.	5590.	9840.	7340.	68.5	.942	1.229
18.0	9.26	8790.	6560.	11540.	8610.	72.5	.942	1.229
19.0	9.77	10260.	7650.	13470.	10050.	76.5	.942	1.229
20.0	10.29	12040.	8980.	15800.	11780.	80.5	.942	1.229
21.0	10.80	14090.	10510.	18490.	13790.	84.8	.943	1.229
22.0	11.32	16530.	12320.	21690.	16170.	89.2	.945	1.228
23.0	11.83	19480.	14520.	25560.	19050.	93.5	.952	1.226
23.1	11.88	19810.	14770.	25990.	19380.	94.1	.953	1.225
24.0	12.35	23140.	17250.	30370.	22640.	98.5	.962	1.219
25.0	12.86	27610.	20590.	36280.	27050.	104.2	.978	1.209
26.0	13.38	32760.	24430.	43280.	32270.	110.1	1.003	1.196

SHIP SPEED (KNOTS)	EFFICIENCIES(ETA) ETAS	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
16.0	.760	.700	1.050	1.035	.900	.855	.880	1.025
17.0	.760	.705	1.045	1.035	.900	.860	.880	1.030
18.0	.760	.710	1.040	1.035	.900	.865	.885	1.035
19.0	.760	.710	1.040	1.035	.900	.865	.890	1.040
20.0	.760	.710	1.040	1.035	.900	.865	.890	1.035
21.0	.760	.705	1.040	1.035	.900	.865	.890	1.035
22.0	.760	.705	1.045	1.040	.900	.865	.890	1.025
23.0	.760	.695	1.050	1.045	.900	.860	.885	1.015
23.1	.760	.695	1.050	1.045	.900	.860	.885	1.015
24.0	.760	.690	1.050	1.055	.900	.855	.885	1.005
25.0	.760	.685	1.050	1.065	.900	.860	.895	.995
26.0	.755	.680	1.040	1.070	.900	.865	.900	.985

Table 16

FULL LOAD DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE LIPS DESIGN PROPELLERS FROM THE NOVEMBER 1978 PROPULSION EXPERIMENTS (MODEL 5362 WITH PROPELLERS LIPS 9019 AND 9020)

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER(PE) (HORSE-POWER)	EFFECTIVE POWER(PE) (KILO-WATTS)	DELIVERED POWER(PD) (HORSE-POWER)	DELIVERED POWER(PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE	T_F/T_A	Q_F/Q_A
16.0	8.23	6330.	4720.	8270.	6170.	64.8	1.027	1.069
17.0	8.75	7500.	5590.	9810.	7310.	68.8	1.036	1.079
18.0	9.26	8790.	6560.	11500.	8570.	72.9	1.045	1.089
19.0	9.77	10260.	7650.	13420.	10010.	76.9	1.053	1.099
20.0	10.29	12040.	8980.	15740.	11730.	81.1	1.063	1.109
21.0	10.80	14090.	10510.	18420.	13740.	85.3	1.073	1.119
22.0	11.32	16530.	12320.	21600.	16110.	89.5	1.083	1.129
23.0	11.83	19480.	14520.	25460.	18980.	94.0	1.093	1.139
23.1	11.88	19810.	14770.	25890.	19310.	94.5	1.095	1.140
24.0	12.35	23140.	17250.	30330.	22610.	99.0	1.101	1.149
25.0	12.86	27610.	20590.	36330.	27090.	104.7	1.111	1.159
26.0	13.38	32760.	24430.	43340.	32320.	110.7	1.120	1.169

SHIP SPEED (KNOTS)	EFFICIENCIES(ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
16.0	.765	.720	1.015	1.045	.860	.845	.865	1.005
17.0	.765	.720	1.010	1.050	.860	.850	.870	1.010
18.0	.765	.725	1.005	1.050	.860	.855	.875	1.015
19.0	.765	.725	1.005	1.050	.860	.855	.875	1.020
20.0	.765	.725	1.005	1.050	.860	.855	.875	1.020
21.0	.765	.720	1.005	1.055	.860	.855	.875	1.015
22.0	.765	.720	1.010	1.055	.860	.850	.870	1.010
23.0	.765	.715	1.015	1.055	.860	.845	.870	1.000
23.1	.765	.715	1.015	1.055	.860	.845	.870	1.000
24.0	.765	.710	1.015	1.060	.855	.845	.870	.990
25.0	.760	.705	1.010	1.070	.855	.850	.875	.975
26.0	.755	.700	1.000	1.080	.855	.855	.885	.965

Table 17

FULL LOAD DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE LIPS DESIGN PROPELLERS FROM THE APRIL 1979 PROPULSION EXPERIMENTS (MODEL 5362 WITH PROPELLERS LIPS 9019 AND 9020)

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER(PE) (HORSE-POWER)	EFFECTIVE POWER(PE) (KILO-WATTS)	DELIVERED POWER(PD) (HORSE-POWER)	DELIVERED POWER(PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE	T_F/T_A	Q_F/Q_A
16.0	8.23	6330.	4720.	8270.	6170.	64.6	1.160	1.160
17.0	8.75	7500.	5590.	9810.	7310.	68.6	1.160	1.160
18.0	9.26	8790.	6560.	11500.	8570.	72.6	1.160	1.161
19.0	9.77	10260.	7650.	13420.	10010.	76.7	1.160	1.163
20.0	10.29	12040.	8980.	15740.	11730.	80.7	1.161	1.165
21.0	10.80	14090.	10510.	18420.	13740.	85.0	1.164	1.169
22.0	11.32	16530.	12320.	21600.	16110.	89.2	1.168	1.175
23.0	11.83	19480.	14520.	25460.	18980.	93.8	1.171	1.182
23.1	11.88	19810.	14770.	25890.	19310.	94.3	1.172	1.183
24.0	12.35	23140.	17250.	30370.	22640.	98.8	1.175	1.192
25.0	12.86	27610.	20590.	36710.	27380.	104.5	1.178	1.202
26.0	13.38	32760.	24430.	44270.	33020.	110.4	1.181	1.213

SHIP SPEED (KNOTS)	EFFICIENCIES(ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
16.0	.765	.740	1.090	.945	.950	.870	.850	1.040
17.0	.765	.745	1.085	.945	.950	.875	.855	1.045
18.0	.765	.745	1.085	.950	.950	.875	.860	1.050
19.0	.765	.745	1.080	.950	.950	.880	.860	1.050
20.0	.765	.745	1.080	.950	.950	.880	.860	1.050
21.0	.765	.745	1.080	.950	.950	.880	.860	1.045
22.0	.765	.745	1.085	.950	.950	.875	.855	1.040
23.0	.765	.740	1.085	.955	.950	.875	.855	1.035
23.1	.765	.740	1.085	.955	.950	.875	.855	1.035
24.0	.760	.735	1.080	.955	.945	.875	.855	1.025
25.0	.750	.730	1.070	.960	.935	.875	.860	1.010
26.0	.740	.725	1.055	.965	.925	.875	.860	.995

Table 18

FULL LOAD DISPLACEMENT POWERING CHARACTERISTICS FOR THE STRETCHED PONCE DE LEON (SPDL) CLASS RO/RO SHIP WITH THE LIPS DESIGN PROPELLERS IN THE DTNSRDC PROPELLER DESIGN POSITION (FORWARD) FROM THE APRIL 1979 PROPULSION EXPERIMENTS (MODEL 5362 WITH PROPELLERS LIPS 9019 AND 9020)

SHIP SPEED (KNOTS)	SHIP SPEED (M/SEC)	EFFECTIVE POWER (PE) (HORSE-POWER)	EFFECTIVE POWER (PE) (KILO-WATTS)	DELIVERED POWER (PD) (HORSE-POWER)	DELIVERED POWER (PD) (KILO-WATTS)	PROPELLER REVOLUTIONS PER MINUTE	T_F/T_A	Q_F/Q_A
16.0	8.23	6330.	4720.	8170.	6090.	64.6	1.215	1.177
17.0	8.75	7500.	5590.	9680.	7220.	68.6	1.215	1.177
18.0	9.26	8790.	6560.	11350.	8460.	72.6	1.215	1.177
19.0	9.77	10260.	7650.	13250.	9880.	76.7	1.215	1.179
20.0	10.29	12040.	8980.	15530.	11580.	80.8	1.215	1.180
21.0	10.80	14090.	10510.	18180.	13560.	85.0	1.216	1.182
22.0	11.32	16530.	12320.	21330.	15900.	89.2	1.220	1.185
23.0	11.83	19480.	14520.	25130.	18740.	93.7	1.229	1.189
23.1	11.88	19810.	14770.	25560.	19060.	94.2	1.230	1.189
24.0	12.35	23140.	17250.	29890.	22290.	98.7	1.238	1.192
25.0	12.86	27610.	20590.	35900.	26770.	104.5	1.247	1.196
26.0	13.38	32760.	24430.	43000.	32060.	110.4	1.256	1.200

SHIP SPEED (KNOTS)	EFFICIENCIES (ETA) ETAD	ETAO	ETAH	ETAR	THRUST DEDUCTION AND WAKE FACTORS 1-THDF	1-WFTT	1-WFTQ	ADVANCE COEF. ADVC
16.0	.775	.745	1.110	.935	.975	.880	.855	1.050
17.0	.775	.745	1.105	.940	.975	.880	.860	1.055
18.0	.775	.745	1.100	.940	.975	.885	.865	1.055
19.0	.775	.745	1.100	.945	.975	.890	.865	1.060
20.0	.775	.745	1.100	.945	.975	.890	.865	1.060
21.0	.775	.745	1.100	.945	.975	.885	.865	1.055
22.0	.775	.745	1.105	.945	.975	.880	.860	1.050
23.0	.775	.745	1.105	.945	.975	.880	.860	1.040
23.1	.775	.740	1.105	.945	.975	.880	.860	1.040
24.0	.775	.740	1.105	.950	.970	.880	.860	1.030
25.0	.770	.735	1.090	.955	.965	.885	.870	1.025
26.0	.760	.730	1.075	.965	.960	.890	.875	1.010

Table 19

Comparison of Ballast Displacement Powering Characteristics with the Single Screw Propeller to those with the LIPS and DTNSRDC Design Contrarotating Propellers

V_S (KNOTS)	$\frac{P_{E_{CR}}}{P_{E_{SS}}}$	$\frac{P_D \text{ (LIPS)}}{P_{D_{SS}}}$	$\frac{P_D \text{ (DTNSRDC)}}{P_{D_{SS}}}$
16.0	1.000	0.885	0.880
17.0	1.000	0.885	0.880
18.0	1.000	0.880	0.875
19.0	0.995	0.875	0.870
20.0	0.990	0.875	0.870
21.0	0.990	0.870	0.870
22.0	0.990	0.875	0.870
23.0	0.990	0.875	0.875
23.1	0.990	0.880	0.875
24.0	0.990	0.885	0.880
25.0	0.995	0.900	0.890
26.0	1.000	0.915	0.890

CR - Contrarotating
SS - Single Screw

APPENDIX A

METHODS USED IN FAIRING THE DATA

Figures 35 to 43 show plots of the model test data and the corresponding faired curves. The data include the propulsive coefficient η_D, apparent advance coefficient J_V, torque ratio Q_F/Q_A, thrust ratio T_F/T_A, relative rotative efficiency η_R, and thrust deduction 1-t, plotted as a function of ship speed. The figures showing the data from the experiments with the model fitted with the DTNSRDC design contrarotating propellers show both the faired curves and the curves using the corrected η_D values (reported data curves).

Generally, the data showed more scatter as the speed decreased. This is due to the relatively small magnitude of the quantities measured, making it difficult to get accurate results.

The thrust deduction curves are faired through the data at the higher speeds, and assumed constant at the lower speeds. There is more scatter in the thrust deduction data from April than from November, even though the faired thrust deduction values from the April experiments seem more reasonable. Some of the thrust deduction values from April seem unrealistic, having values close to or greater than 1.0. These unrealistic values usually occur at the lower speeds where the thrust measurements are less accurate because of their small magnitude.

The plots of the thrust and torque ratios include both the open water and propulsion experiment curves. The shape of the open water thrust and torque ratio curves are used as guides in fairing curves through the thrust and torque ratio data from the propulsion experiments.

The thrust and torque ratio curves follow the calculated values from the propulsion experiments reasonably well. The only exception was the thrust ratio of the LIPS propellers from April, Figures 41 and 42. As the speed decreased, the thrust ratio values sharply increased. This is different than the curves from November, where the thrust ratio slowly decreased with decreasing speed. The open water thrust ratio curve was used as a guide to fair these curves.

During the November 1978 propulsion experiments, the data was taken in the standard way; after each data spot, the carriage speed was increased. However, during the April 1979 propulsion experiments the carriage speed was increased after three or four data spots were taken

during each pass down the basin. The second method allows more data to be taken during each pass down the basin since the propeller rpm and towing force (F_D) does not have to be frequently changed. However, because many of the speeds were later repeated, some of the data points became clustered on plots, which made it difficult to fair a line.

No loads were taken at the beginning and end of each experiment, and every four hours during each experiment. Bollards were taken at 200 rpm (model scale) before each pass down the basin. Plots of the bollard values (thrusts and torques) versus the number of passes down the basin were used as guides in selecting the correct noload values.

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